THE NICKEL BULLETIN

A Monthly Summary of Recent Literature

DECEMBER

1959 Volume 32 No. 12

THE MOND NICKEL COMPANY LIMITED

THAMES HOUSE MILLBANK LONDON SW1

Telephone: VICtoria 3888

CONTENTS LIST

Nickel Page

Recrystallisation of Nickel 349
Creep Behaviour of Nickel and Nickel-Cobalt Single Crystals 349
Investigation of the Nickel-Cadmium Cell 349

Electrodeposition and Other Coating Methods

Electrodeposited Nickel Coatings: Revised British Standard 350
B.N.F. Plating Gauge 351
Atmospheric Corrosion of Nickel-Plated Steel Sheet 352
Structural Studies of Nickel, Chromium and Silver Electrodeposited Coatings 353
Anodic Behaviour of Various Grades of Electrolytic Nickel 353
Influence of Impurities on Bright-Nickel-Plating Solutions 354
Influence of Calcium and Copper on the Properties of Nickel Electrodeposits 354
Influence of Manganese on the Properties of Nickel Electrodeposits 355

Non-Ferrous Alloys

Report of the Royal Mint: Nickel-containing Coinage 355
Improved Nickel-containing Gunmetals for Quality Castings 356
Age-Hardening and Tensile Properties of Nickel-Tin-Bronze Sand Castings 356

Nickel-Iron Alloys

Magnetic Properties of Metals and Alloys 357
Effects of Temperature on Magnetic-Core Materials 357
Magnetic Annealing in Iron-Cobalt-Nickel Alloys 358

Cast Iron

Use of 'Ni-Hard' for Grinding-Mill Liners 358

Constructional Steels

Investment Castings in Carbon- and Low-Alloy Steel: British Standard 359
Temper-Embrittlement: Literature Review 359
Internal Friction and Temper Brittleness in Low-Alloy Steel 359
Elevated-Temperature Properties of Cast and Wrought High-Strength Steels 359
Influence of Structural Variables on the Properties of High-Strength Cast Steel 360
Influence of Small Forging Reductions on the Properties of Nickel-Chromium-Molybdenum Steel 360
Control of Austenitic Grain-Size in Medium-Carbon and Carburising Steels 361
Development, Properties and Applications of Basic Low-Hydrogen Electrodes 361

Heat- and Corrosion-Resisting Materials

Symposium on High-Temperature Materials 362
Status and Future of Nickel-base Alloys 362
Influence of Alloying Additions on the Stress-Rupture Properties of Nickel-Chromium-Iron-Cobalt-base Alloys 362
Suitability of 'Guy Alloy' for Use in Turbine Blades 362
'W-545': Iron-Nickel-Chromium-base High-Temperature Alloy 363
History, Status and Future of Cobalt-base Alloys 363
Properties of 'ML-1700' Cobalt-base Casting Alloy 363
Temperature Dependence of Secondary Phases in High-Temperature Alloys 363
Cermets and Bonded Hard Metals 363
Sintered Nickel/Titanium-Carbide Compositions 363
Titanium-Carbide Compositions Infiltrated with High-Temperature Alloys 364
Wettability and Microstructural Studies in Liquid-Phase Sintering 364
Fracture and Slip in Nickel-containing Cemented Carbides 364

Heat- and Corrosion-Resisting Materials (*contd.*) Page

High-Temperature Materials Based on Intermetallic Compounds 364
Evaluation of Nickel-containing Cermet Turbine Blades 365
Developments in Chromium-base Alloys 365
Influence of Alloying Additions on the Transition Temperature of Chromium 365
Molybdenum, Its Alloys and Its Protection 365
Properties of Molybdenum-Alloy Turbine Blades 366
Processing and Properties of Molybdenum-base Alloys 366
Properties of Tungsten, Tantalum, Niobium and Rhenium 366
Factors Involved in Dispersion Hardening 366
Dispersion Hardening of Titanium 366
Effects of Vacuum Melting on Cast Nickel-base Alloys 366
Evaluation of Nickel-base Alloys Melted and Investment-Cast in Vacuo 366
Consumable-Electrode Vacuum Melting of Nickel-base High-Temperature Alloys 367
Influence of Crucible Materials on Vacuum-Melted Nickel-base Alloys 367
Effects of Vacuum Melting on the High-Temperature Properties of Nickel-base Alloys 367
Influence of Environment on the Creep Properties of Nickel and Nickel-base Alloys 368
Creep-Rupture Properties of Nickel in Air and in Vacuo 368
Influence of Sodium Hydroxide, Air and Argon on the Stress-Rupture Properties of Nickel 368
Creep-Rupture Properties of Molybdenum Alloys in Helium and in Vacuo 368
Influence of Alloying Additions on the Oxidation Resistance of Chromium 368
Oxidation of Tungsten and Molybdenum 369
Film Formation and Oxide Growth on Nickel-containing Gas-Turbine Alloys 369
Spectral Emittance of 'Inconel' and Austenitic Stainless Steel 369
Fatigue-Strength of Heat-Resisting Alloys at Elevated Temperatures 370
Influence of Boron and Zirconium Additions on the Properties of a Nickel-base Heat-Resisting Alloy 370
Influence of Directional Grain Structures on the Creep-Rupture Properties of a Cast Nickel-base Alloy 370
Creep Properties of Molybdenum-containing Austenitic Steels 371
High-Temperature Compressive Strength of Stainless-Steel Sandwich Structures 371
Evaluation of Austenitic-Steel Superheater Tubing After Long-Time Exposure to Steam at High Temperatures 372
Use of 'Inconel 713C' for Hot Dies in Press Forging 372
Surface Treatments for Hot-Work Dies 373
Press Forging of Cast '17-4 P.H.' and 18-8-type Stainless Steels 373
Machining of 'Nimonic' Alloys and Ultra-High-Tensile Steels 374
Effects of Radiation on the Properties of Ferrous Materials 374
Factors Influencing Stress-Corrosion Cracking of Stainless Steel 374
Inhibition of Chloride Stress Corrosion of Stainless Steel 375
Corrosion-Resistance of Nickel-containing Aluminium Alloys 375
Polishing and Buffing of Nickel-containing Materials 376
Welding of 'Nimonic' Alloys 376
Welding of 'Hastelloy B', 'Hastelloy N' ('INOR 8') and 'Hastelloy W' 376
Fusion Welding of Precipitation-Hardening Stainless Steels 377

Index to Volume 32 379

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

NICKEL

Recrystallisation of Nickel

W. BOLLMAN: 'Electron-Microscopic Observations on the Recrystallisation of Nickel.'

Jnl. Inst. Metals, 1959, vol. 87, Aug., pp. 439–43.

The various stages in the recrystallisation of nickel were studied, by transmission electron microscopy, on rolled 0·1-mm.-thick sheet treated for 30 minutes in air at temperatures up to 400°C., and then in pure hydrogen at higher temperatures. Some treatments were repeated *in vacuo*.

The hardness/annealing-temperature curve obtained could be divided into three distinct sections (room temperature to 250°C., 250° to 400°C., and temperatures higher than 400°C.), associated, respectively, with recovery, primary recrystallisation and secondary recrystallisation. The initial part of the recovery curve could be correlated with the process of polygonisation initiating in a cloudy distribution of dislocations. Observations on the nucleation of crystal grains were explicable essentially on the basis of the theories of Cahn and Cottrell, but, contrary to Cahn's assumption, polygonisation did not constitute a preliminary stage of recrystallisation, since, from a given moment, polygonisation and recrystallisation developed simultaneously until the whole volume was consumed by the crystal grains.

Inside the crystal grains certain phenomena (termed 'growth zones' and probably originating from segregated impurities and/or local disorder, i.e., a higher concentration of point defects) became visible and furnished indications of the history of the grains. Stages in grain-growth during primary recrystallisation, and displacement of grain boundaries during secondary recrystallisation, could thus be observed.

Creep Behaviour of Nickel and Nickel-Cobalt Single Crystals

M. MICHELITSCH: 'The Creep Behaviour of Single Crystals of Face-Centred-Cubic Metals.'

Zeitsch. f. Metallkunde, 1959, vol. 50, Sept., pp. 548-60.

The paper presents the results of creep tests carried out to determine, on a quantitative basis, the relationship between creep behaviour and the temperature and degree of deformation. The tests were carried out, at room- and high temperature, on single crystals of nickel, aluminium, copper, and a nickel-cobalt alloy containing 20 at. per cent. of cobalt.

The curves obtained show the first stage of creep to be logarithmic, the second hyperbolic ($m \approx 1 \cdot 1$). and the third parabolic ($m < 1$). The work-hardening coefficient ϑ is at a maximum in the I–II transition stage, and then falls, by about 25 per cent., to a constant value in stage II.

The activation volume determined from logarithmic creep-rate/time curves for the first stage of creep differed from that established by experiments in which the temperature was varied during testing. This discrepancy is resolved on the basis that the creep rate is determined by a spectrum of activation volumes or energies.

Creep-Rupture Properties of Nickel in Air and in Vacuo

See abstract on p. 368.

Influence of Environment on the Creep Properties of Nickel

See abstract on p. 368.

Influence of Sodium Hydroxide, Air and Argon on the Stress-Rupture Properties of Nickel

See abstract on p. 368.

Investigation of the Nickel-Cadmium Cell

A. J. SALKIND: 'Investigation of the Nickel-Cadmium Cell.'

Polytechnic Inst. of Brooklyn, Thesis, June 1958; 157 pp.

Obtainable from *University Microfilms, Inc.*, Ann Arbor, Michigan.

The aim of the investigation was two-fold: (1) to determine the reactions and kinetics of the nickel-cadmium cell, and (2) to develop a separator which would be unaffected by the presence of copper impurities in the cell electrodes.

The solid reaction products of the nickel-cadmium electrodes were studied by X-ray techniques, using special equipment and methods which permitted X-ray films and diffractometer patterns to be obtained from electrodes while in service and in any state of charge or discharge. Open-circuit voltage decay measurements for the individual half-cells were made at temperatures in the range 0°–125°F. (−18° to 50°C.) by means of specially constructed mercury/mercuric-oxide control electrodes. The effects, on cell performance and charge reduction, of plate spacing, electrolyte concentration, and separator material were determined using cells of 'Sandia' type having a nominal capacity of 5 ampere-hours.

Test procedures are described, and full details are given of the extensive data obtained from the experiments. The author's findings are summarised as follows:

'1. The reaction in the nickel-cadmium cell is:

$$2\,Ni(OH)_2 + Cd(OH)_2 \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} 2\,NiOOH + Cd + 2\,H_2O$$

'2. The active nickel hydroxides of the nickel electrode are in solid-state solution, and the potential of the nickel electrode depends on the relative amounts of each of the hydroxides.

'3. $Ni(OH)_2$ becomes less crystalline on charging. The charge process involves the loss of a proton, which, permitting the layers of nickel atoms to separate, causes an increase in the 'C' dimension of the crystal and leads to disorientations.

'4. The nickel electrode has a negative coefficient of change of voltage with temperature. The magnitude of this change is much larger than that of the negative electrode and controls the overall cell potential.

'5. The overall cell voltage was increased when 20 per cent. KOH electrolyte was substituted for the standard 31 per cent. KOH electrolyte, but the charge-retention characteristics of the cells were adversely affected.

'6. The heat of reaction of the nickel-cadmium cell is -62 KCal./gm. mole.

'7. The heat of formation of NiOOH, determined from a plot of E/T *vs.* the logarithm of the vapour pressure of water, is -158 KCal./gm. mole.

'8. The high rate discharge capacity and the available surface area on the electrodes are affected by the charge rate. Five-ampere-hour nickel-cadmium cells delivered below-normal capacities at the 28-ampere discharge rate to the 1·0 volt cut off when charged at a current rate less than 1·0 ampere.

'9. Cells assembled with 'Polypor'* separator delivered better all around performances than cells assembled with any other type of separator, experimental or standard.

'10. 'Polypor WA', 'Polpypor WB' and 'Polypor MPD' are suitable separator materials for preventing the formation of shorts in cells, when the shorts are caused by copper contamination in the cell electrodes.

'11. The constant b in the Tafel equation is temperature dependent. A curve has been determined which can be used to evaluate this constant between the limits of 0°F. and 125°F. ($-18°$ and 50°C.).'

Polishing and Buffing of Nickel

See abstract on p. 376.

* Microporous material made from polyvinyl alcohol and dynel resin.

ELECTRODEPOSITION AND OTHER COATING METHODS

Electrodeposited Nickel Coatings: Revised British Standard

BRIT. STANDARDS INSTN.: 'Electroplated Coatings of Nickel and Chromium.'

B.S. 1224: 1959; 19 pp. Price 5/-.

This British Standard lays down requirements (with respect to appearance, thickness, adhesion, corrosion-resistance and ductility) for nickel coatings electrodeposited on steel, copper, brass or zinc alloy. With the exception of those fabricated from stainless steel, articles which are to be chromium plated must first receive a standard coating of nickel. The following coatings are excluded from the scope of the Standard: those applied to components having threads of basic major diameter in the range 0·05–0·5 in. (1·25 mm.–1·25 cm.), those applied to sheet, strip, wire in unfabricated form, or coil springs, and those for engineering purposes (e.g., 'hard chromium').

The Standard was first published in 1945. It was revised in 1953 (partly because the original Standard had not fully met the requirements of the automobile industry), and, as a result of the demand for thicker coatings of nickel and the availability of new methods for testing the coatings, a further revision has now become necessary. An essential difference between this revision and the previous standard is that the salt-spray test is now supplemented by the acetic-acid/salt-spray and the sulphur-dioxide corrosion tests.

An important feature of the Standard is the minimum thickness specified for the nickel deposit. Particular attention is drawn to the effect of contour, and, in general, the requirements for minimum thickness apply only to those portions of the significant surface which can be touched by a ball of 1-in. (2·5-cm.) diameter. If the design of the article is such that this 1-in.-ball criterion cannot be satisfied, the minimum thickness permitted on specified areas should be arranged between manufacturer and purchaser.

It has not been found possible to specify average thicknesses, since these vary with the size and shape of the article and the method of plating. Due to variations in requirements, it was also deemed impracticable to give definite information on the classifications which should be chosen for particular applications, but broad guidance on the kind of service conditions for which each coating is suitable is given in a table, *reproduced on p. 351*, which contains details of minimum nickel thicknesses. Classification of the coatings is in all cases based on nickel thickness, and it is essential that the purchaser should state the appropriate classification number.

Details are given in the Standard of eight test procedures stipulated for evaluating the thickness and properties of the deposit: (A) a local thickness test (which permits accurate measurement of the thickness of the deposit by metallographic examination of a

B.S. 1224: 1959 : Minimum Local Thickness of Nickel Coatings

(*See abstract on p. 350*)

Basis Metal	Classification of Coating	Minimum Local Thickness Inches		Appropriate Service	Minimum Local Thickness Millimetres	
		Without Undercoat	With 0·0003-in. Copper Undercoat		Without Undercoat	With 0·0075-mm. Copper Undercoat
Steel	Ni 12S, Ni 12SB*	0·0012	0·0010	Severe	0·030	0·025
	Ni 8S	0·0008	0·0006	Moderate	0·020	0·015
	Ni 4S	0·0004	†	Mild	0·010	†
Copper or Brass	Ni 6C	0·0006	†	Severe	0·015	†
	Ni 3C	0·0003	†	Moderate	0·008	†
Zinc Alloy	Ni 10Z	‡	0·0010	Severe	‡	0·025
	Ni 6Z	‡	0·0006	Moderate	‡	0·015
	Ni 3Z	‡	0·0003	Mild	‡	0·0075

* Ni 12SB signifies buffed ductile semi-bright nickel, or alternatively, a copper undercoat followed by ductile nickel, either copper or nickel having been buffed.

† A copper undercoat is not precluded from classifications Ni 4S, 6C and 3C, but the specified minimum local thickness of nickel must be maintained.

‡ By agreement, the copper undercoat may be omitted from Ni 10Z, Ni 6Z and Ni 3Z, provided that the rest of the specification is met.

sectioned sample); (B) a burnishing test for adhesion; (C) a file test for adhesion; (D) a quenching test for adhesion; (E) a sulphur-dioxide corrosion test; (F) an acetic-acid/salt-spray corrosion test; (G) a salt-spray test; (H) a ductility test.

Local thickness of the nickel deposit is measured by method A, and adhesion by any of methods B, C and D. The corrosion-resistance of coatings to classifications Ni 12S, Ni 8S and Ni 10Z is evaluated by any one of methods E, F and G, but that of classification Ni 6C only by method E. The letter 'D' can be added to any classification to specify a ductile coating of nickel, which is then liable to test by method H.

Chromium coatings on nickel-plated or stainless-steel articles shall be not less than 0·00001 in. (0·00025 mm.) thick, with the exception of components having a basic diameter of less than $\frac{1}{2}$ in. and plated to Ni 4S or Ni 3C, to which, provided the chromium deposit covers the whole surface, the thickness requirement does not apply.

For control purposes, testing methods other than those described are permissible, and attention is drawn to the B.N.F. jet test and thermoelectric thickness meter. In this connection, see following abstract.

B.N.F. Plating Gauge

'B.N.F. Plating Gauge.'

Pamphlet issued by *The British Non-Ferrous Metals Research Association*, Nov. 1959.

This pamphlet is of interest in connection with the publication of *B.S.* 1224:59 (see preceding abstract). It gives details of the B.N.F. Plating Gauge, manufacture of which, in its modified form, is being undertaken under licence by Nash & Thompson, Ltd., Tolworth, Surrey.

Originally developed some three or four years ago as a laboratory instrument for determining the thickness of electroplated coatings, the B.N.F. Plating Gauge has recently been substantially modified and re-designed to make it a robust, routine inspection tool for measuring the thickness of nickel electrodeposits on steel, brass or zinc-alloy die castings, a purpose for which it is rapid, accurate and completely non-destructive.

Once adjusted for the particular combination of coating and basis metal being inspected, it can be placed in the hands of quite unskilled personnel, the only operations required being to apply the spring-loaded probe with the special jig and read off from the meter the thickness of nickel. Nickel

thickness can be measured with an accuracy of ±0·0001 in. (±0·0025 mm.) for the nickel ranges covered by *B.S.* 1224. Readings can be made in quick succession, as rapidly as one every five seconds if necessary, making thorough inspection of nickel-plated parts a practical proposition.

The probe tip is a hard steel hemisphere less than ⅛ in. (0·3 cm.) in diameter, and its small area of contact enables highly localised measurements to be made. Curved surfaces present no difficulty, so that variations in nickel thickness over an article of complex shape can be determined. Life tests have demonstrated that at least 100,000 readings can be made before replacement of the probe tip has to be considered. The positive spring-loading of the probe makes it insensitive to vibration from nearby machinery.

The instrument utilises the thermo-electric properties of the junction formed between the plating and the basis metal. A copper probe, terminating in a small hemispherical steel tip and heated to constant temperature by a small electrical winding, is applied to the plated article. Because the temperature of the plating/basis-metal interface is dependent on the thickness of nickel immediately beneath the heated probe, the thermo-electric potential generated between the hot probe and a cold part of the plated article varies with the coating thickness. This thermo-electric potential, which is only about 1 millivolt, is amplified electronically and shown on a meter with three scales calibrated directly in terms of nickel thickness on steel, brass or zinc, respectively.

In use, the instrument is zeroed, using two standards provided, and the zero control is then locked. Differences in the thermo-electric properties of the coatings and basis metals can be accommodated by adjusting only one control on the instrument, set by reference to a third standard (provided by the user) which is similar to and has the same composition of nickel as the articles to be inspected. Experience to date is that, even if this third standard is not available, measurements can still be made with an accuracy of ±0·0002 in. (±0·005 mm.), though there may be nickel compositions not yet examined which fall outside this range. The safest procedure is to standardise finally on the type of nickel deposit under examination, and an accuracy of ±0·0001 in. (±0·0025 mm.) nickel is then realised.

Atmospheric Corrosion of Nickel-Plated Steel Sheet

E. RAUB, F. ELSER and G. SCHMIDT: 'Atmospheric Corrosion Tests on Nickel-Plated Steel Sheet.' *Metalloberfläche*, 1959, vol. 13, Oct., pp. 330–6.

The tests, the results of which are summarised in the present paper, were carried out to determine the influence, on the corrosion-resistance of matt-nickel coatings, of (1) the variables involved in the preliminary degreasing operation, (2) the use of killed or rimmed steel for the basis metal, and (3) of copper plating prior to deposition of the nickel coating.

The coatings evaluated were deposited on sheet cold-rolled from six grades of steel, two of which had been killed with silicon and one with aluminium; the remaining three were rimmed. Prior to plating, the specimens were anodically or cathodically degreased at room temperature or 90°C., using a current density of 5 amp./dm.², in an electrolyte of the following composition: sodium hydroxide 60, sodium carbonate 30, g/L. The effects of the degreasing procedure were evaluated by varying the period and temperature at which the specimens were subjected to anodic and/or cathodic treatment. The specimens were exposed to atmospheric corrosion (in a location representative of a mild industrial town environment) in three conditions: matt-nickel-plated to an average thickness of 20 μ without subsequent treatment; matt-nickel-plated and polished; copper-plated and finally nickel-plated, both coatings being deposited to a thickness of 10 μ and then polished. (Some of the 5,000 specimens studied were subjected to accelerated-corrosion tests, the results of which will be described in a future paper.) Corrosion-resistance was assessed in terms of the number of rust spots visible to the naked eye after two and twelve months' exposure. Photographs of the test specimens illustrate the degree of corrosion suffered.

On the basis of the data obtained, and within the limits imposed by the experimental conditions studied, the authors conclude that the copper/nickel composite coatings exhibited a higher corrosion-resistance than a single nickel deposit of similar thickness. (It is emphasised, however, that the intermediate copper deposit was polished.) The number of larger-size rust spots was less on the composite coatings, but there also appeared to be a greater tendency to rust formation at surface defects beneath the deposit.

Under similar pre-treatment and nickel-plating conditions, specimens of open-hearth steel exhibited a somewhat higher corrosion-resistance than Bessemer-steel sheet, and the corrosion-resistance of nickel-plated killed steel was, in general, found to be less than that of rimmed-steel specimens. These distinctions, however, were not very pronounced, and virtually disappeared with the introduction of an intermediate layer of copper: signs of severe rusting were found only in aluminium-killed steel.

The different electrolytic degreasing procedures had no pronounced effect on the corrosion-resistance of the nickel-plated steel provided the degreasing and cleaning were effectively carried out. Variations in the degreasing procedure were, however, reflected in the mode of corrosion of the different types of steel. Anodic degreasing or alternate cathodic and anodic degreasing of silicon- or aluminium-killed steels increased susceptibility to filamentary corrosion and to rusting beneath the coating. A tendency to filamentary corrosion was observed also after hot cathodic degreasing, and this phenomenon is attributed to the fact that at high degreasing temperatures remnants of the electrolyte dry on the sheet, are difficult to remove, and, as impurities, favour filamentary corrosion under the nickel layer.

Structural Studies of Nickel, Chromium and Silver Electrodeposited Coatings

E. RAUB, M. MIETKA and H. BEESKOW: 'Studies of the Structure of Thin Electrodeposited Coatings.' *Metalloberfläche*, 1959, vol. 13, Oct., pp. 321–7.

The investigation reported was conducted with the aim of studying the structure of thin metallic films electrodeposited on to a surface intended to minimise reproduction of the features of the substrate.

Coatings of nickel, chromium and silver 50–30 Å thick were deposited on copper plate which, after cold-working or cold-working and annealing, had been mechanically, anodically or chemically polished. In some cases the coatings were deposited on a copper substrate in the cold-worked-and-annealed condition. After removal from the substrate, the metal films were subjected to electron-microscopical examination. Photomicrographs illustrating the authors' findings are included in the paper.

The metals, when deposited on mechanically-polished copper plates, were initially polycrystalline and disordered. Crystallites of bright-nickel deposits were considerably finer than those of matt-nickel films, and the former exhibited a clear orientation, independent of the orientation of the substrate, at a thickness at which the matt-nickel deposits were still unoriented.

The stresses present in chromium coatings deposited on structured copper basis metal were reflected, even in very thin films, by indications of the type of hair cracks characteristic of thick coatings.

'Negative' crystallites (faults in the coating at which no further deposition occurred) were observed during electrolytic crystallisation, particularly in the case of nickel and silver. Crystallites of matt-nickel coatings deposited on structured copper exhibited a step-like growth.

Anodic Behaviour of Various Grades of Electrolytic Nickel

E. RAUB and A. DISAM: 'The Anodic Behaviour of Various Grades of Electrolytic Nickel.' *Metalloberfläche*, 1959, vol. 13, Oct., pp. 308–14.

In an earlier investigation by the same authors it was found that an electrolytic-nickel anode dissolved, in electrolytes of various composition, with minimum sludge formation and at a lower polarisation than a depolarised rolled anode (see abstract in *Nickel Bulletin*, 1958, vol. 31, No. 12, pp. 317–18). The work now reported was initiated to investigate the considerable differences in anodic behaviour often exhibited by electrolytic-nickel anodes in practice.

The behaviour of nineteen grades of electrolytic nickel, produced under controlled conditions, was studied. Eleven of the anodes were deposited from three electrolytes, under different conditions of pH, current density or temperature. Four of these were produced from a Watts solution, four from a sulphate-free chloride solution, and the remaining three from a bright-nickel solution of commercially available composition. The other eight anodes were deposited from, respectively, a second commercial bright-plating solution, a nickel-ammonium-sulphate solution, a nickel-cobalt solution (containing 75–80 per cent. of nickel), and from five Watts solutions containing one of the following organic additions: coumarin, sodium-1:3:6-naphthalenetrisulphonate, saccharin, butindiol, and formalin. The plating conditions and the compositions of the electrolytes are tabulated, and the hardness values obtained are discussed.

The anodic behaviour of the fourteen grades of electrolytic nickel was evaluated in a chloride-free nickel-sulphate solution, a sulphate-free nickel-chloride solution, a Watts solution, and a commercial bright-plating solution. The solutions were operated at 20° or 50°C. and a pH of 2 or 4. The anode-potential/currenty-density curves and equilibrium potential determined for each of the grades of anode are presented.

Nickel anodes produced from addition-free chloride and Watts solutions were found to resemble pure rolled anodes in their behaviour, becoming passive in chloride-free sulphate solutions even at low current densities, and the anode potential increasing to the potential of oxygen evolution.

The course of the anode-potential/current-density curves determined for anodes in sulphate-free chloride electrolytes was generally smooth. Under certain conditions, however, the curves were interrupted by a sudden increase in potential without passivation, a phenomenon otherwise encountered only during deposition from sulphate-containing electrolytes. Provided they were free from sulphur, organic additions had relatively little effect on the anodic behaviour of nickel deposited from a Watts solution, even when the mode of crystallisation changed as a result of formation of bright or hard nickel deposits.

Due to co-deposition of nickel sulphide, anodes produced from solutions containing sulphur-bearing organic compounds did not become passive in pure nickel-sulphate solutions even at high anodic current densities, and a similar behaviour was observed in grades of nickel deposited from commercially available bright-nickel solutions, all of which contain sulphur. In many instances, polarisation with these grades of nickel was, irrespective of the composition of the electrolyte, significantly lower than that determined for depolarised rolled anodes.

The anodic behaviour of the cobalt-nickel deposits was intermediate between that of the sulphur-free and sulphur-containing electrolytic grades of nickel. Polarisation was generally more pronounced than that for the sulphur-containing grades, and, under certain operating conditions, they exhibited the previously mentioned 'jump' in potential, particularly in commercial bright-nickel solutions. Anodic polarisation, however, was always significantly lower than that found for the sulphur-free nickel anodes. Nickel anodes deposited from the nickel-ammonium-sulphate solution also exhibited a much lower polarisation than that of anodes produced from the Watts solution or a nickel-chloride electrolyte.

The lattice disturbances occurring during electrodeposition of nickel under the various conditions studied (and reflected, for example, in pronounced differences in hardness) influenced anodic behaviour to a much lesser degree than did the presence of sulphur. Although the effects of such disturbances were clearly evident in some cases, no fundamental differences were found.

The behaviour of anodes deposited from solutions containing organic sulphur compounds was fundamentally different. In general, these sulphur-containing anodes did not become passive in chloride-free sulphate electrolytes even under extreme conditions (e.g., at anodic current densities of 10–15 amp./dm.^{2}), and the mode of dissolution differed from that of the sulphur-free types. The latter were prone to severe pitting at high anodic current densities, whilst on the sulphur-containing types a dark surface film formed under which dissolution progressed uniformly.

Influence of Impurities on Bright-Nickel-Plating Solutions

A. CHAYBANY: 'Some Investigations into Bright Finishing in Nickel Baths and the Influence of Impurities.'

Metal Finishing Jnl., 1959, vol. 5, July/Aug., pp. 263–8.

During work on the electrodeposition of cobalt, the author found considerable differences between the properties of cobalt and nickel coatings, particularly with respect to external appearance and corrosion-resistance. It was observed that cobalt-plating solutions were more easily adapted to deposition of bright deposits than nickel-plating solutions of conventional composition, and in the introductory section of this review the author outlines the reasons for these differences. Emphasis is placed on findings indicating the deleterious effects, on the brightness obtained in the deposits, of chloride additives and of copper and iron impurities present in the plating solution. As a result of these findings, the author carried out research on the development of a chloride-free bright-nickel-plating solution, and on methods of eliminating the copper and iron impurities present in such a solution.

The limiting composition of the solution developed by the author is given as: 7 $H_2O.NiSO_4$ 120–300, ammonium sulphate 20, anhydrous sodium sulphate 100, potassium bromide 1–5, boric acid (if desired) 20–40, g./L. The procedure employed to purify this type of solution, using chemical additives, is described in some detail. Iron is eliminated in the form of the hydroxide, and the copper is precipitated as cuprous thiocyanate. The principal advantage of the bright-plating solutions discussed is stated to be the ease with which the additive agents may be eliminated by simple treatment with permanganates.

The article also includes notes on a method of bright-nickel plating from solutions in which the copper and iron are present in the form of complexes (and hence harmless), and on a process in which iron is eliminated automatically during deposition of nickel-copper alloys.

Influence of Calcium and Copper on the Properties of Nickel Electrodeposits

R. A. BACON: 'The Effects of Impurities on Electrodeposited Nickel with Special Reference to Calcium.' *Michigan University, Department of Metallurgical Engineering, Thesis*, 1957; 64 pp.

Although calcium is commonly present in nickel-plating solutions (mainly as a constituent of hard water used in the make-up of the bath) and is known to have, under certain conditions, an adverse effect on the deposits produced, little work had been carried out to throw light on these effects. Similarly no reason had been advanced in explanation of the black spongy deposits obtained from solutions contaminated with copper. The main emphasis in the investigation now reported was on determination of the effects of calcium on the properties of nickel deposits, but research was also carried out in an attempt to establish the mechanism involved in nodule formation in copper-contaminated plating solutions.

Three types of nickel-plating solution were employed in the study: a Watts-type solution (operated at a pH of 2·2 and 5·2); a nickel-cobalt bright-plating solution (pH 3·75); and an organic-type solution (operated at a pH of 3·2) containing nickel benzene-disulphonate and triaminotolyldiphenylmethane. The influence of cadmium (introduced into the solution as calcium carbonate) was studied at two concentrations: 350 p.p.m. (an average level) and 700 p.p.m. (the upper limit found in plating solutions). Coatings of four different thicknesses were obtained from each solution investigated. The properties of the deposits produced from calcium-contaminated solutions were evaluated in terms of their percentage variation from those exhibited by coatings deposited from the relevant uncontaminated plating solution. It was found that calcium in the amounts used had no significant effect on any of the properties studied (appearance, ductility, hardness and corrosion-resistance of the deposits, and the throwing power of the solutions) and no method was found for removal of the contaminant from the electrolyte.

A solution to the problem of determining the mechanism involved in the formation of nodules on nickel coatings deposited from copper-contaminated plating solutions was sought in a series of experiments designed to isolate the relevant from the irrelevant factors by a process of elimination.

The possibility that the nodules resulted from lattice disturbances was ruled out on the basis of crystallographic and atomic considerations. That the nodules might have originated by imperfections in the basis metal was disproven by several experiments: deposition of a nickel film from an uncontaminated nickel solution to which copper was added as deposition progressed; buffing one half of the basis metal prior to deposition; taper-sectioning the rough black deposit; and altering the direction of solution agitation. In each case the results repudiated any relationship between the basis metal and the nodules. Polarisation studies indicated the formation of hydrides as a likely cause of nodule

growth, and this hypothesis was reinforced by the results of chemical analysis of the nodules and of the smooth nickel coating (the data showed the nodules to have a slightly higher copper content), and by current-density studies which indicated that nodule formation increased at higher current densities. The author concludes from this evidence that this type of roughness in electrodeposited nickel results from a complex solution adjustment at the cathode surface which causes a pH precipitation and localised polarisation differences with subsequent deposition.

Roughness in nickel coatings deposited from solutions contaminated with calcium differed from that in coatings deposited from copper-contaminated solutions, the former occurring by occlusion and entrapment of precipitated salts, probably calcium sulphate.

Influence of Manganese on the Properties of Nickel Electrodeposits

R. J. ROWE: 'The Effects of Manganese on Electrodeposited Nickel.'

Michigan University, Department of Metallurgical Engineering, Thesis, 1956; 52 pp.

Manganese contamination in nickel-plating solutions usually occurs as a result of the presence of manganese in the anodes or as a result of the use of potassium-permanganate additions to overcome organic contamination. The main object of the study reported was to determine the effects of manganese contamination of the electrolyte on the physical properties of nickel deposits, and to investigate electrolytic and high-pH precipitation methods of removing the manganese. The secondary aim was to determine the internal stress of nickel deposited from purified plating solutions, and, in particular, to establish whether highly stressed coatings deposited from a nickel-cobalt solution would crack during plating.

Three electrolytes were selected for study: a Watts solution (operated at a pH of 2·2 or 5·2), an organic bright-plating solution (pH 3·2), and a nickel-cobalt solution (pH 3·75). Manganese was added to each of the solutions in amounts ranging from 0 to 300 mg./L., and a study was made of the influence of these additions on the appearance, adhesion, ductility, hardness and corrosion-resistance of the deposits and on the throwing power of the solution. Corrosion-resistance was evaluated by means of the salt-spray and the acetic-acid/salt-spray tests and by an electrochemical test.

Increase in the manganese concentration of the Watts solution tended to produce finer-grained deposits at the high-current-density areas, but the additions had no effect on the appearance of bright coatings deposited from the nickel-cobalt and organic solutions. Adhesion was unaffected by increase in maganese concentration, but an increase in the ductility of nickel deposited, at a pH of 2·2, from the Watts solution is attributed to the presence of manganese in solution, and in general, there was a decrease in the ductility of deposits produced from the solution operated at a pH of 5·2, and from the nickel-cobalt solution. No significant change was noted in the ductility of nickel from the organic plating solution. Elongation values were unaffected by manganese contamination. The slight variations determined in hardness values are considered of little significance, and the presence of manganese had no effect on corrosion-resistance. Although the throwing power of the two bright solutions increased slightly, no significant trend was established in this connection.

Both high-pH precipitation methods and low-current-density electrolysis were found to be incapable of removing the manganese from the plating solutions.

The internal stress of nickel deposits produced from the solutions studied ranged from a tensile stress of 40,000 p.s.i. (17·8 t.s.i.; 28 kg./mm.^{2}) in the nickel-cobalt coatings to a compressive stress of 5,000 p.s.i. (2·2 t.s.i.; 3·5 kg./mm.^{2}) in the organic bright-nickel deposits. Coatings deposited from the Watts solution exhibited a stress of about 18,000 p.s.i. (8 t.s.i.; 12·5 kg./mm.^{2}). Strain measurements indicated that no cracking occurred in the deposits during plating.

Surface Treatments for Hot-Work Dies

See abstract on p. 373.

NON-FERROUS ALLOYS

Report of the Royal Mint: Nickel-containing Coinage

'Royal Mint: Eighty-ninth Annual Report of the Deputy Master and Comptroller for the Year 1958.' Published by *H.M. Stationery Office*, 1959; 85 pp. + index. Price 5/-.

The report contains the usual statistical information on United Kingdom silver, cupro-nickel, nickel-brass and bronze coinage, currency withdrawn, assays made, etc. Details of the activities of the associated Mints in Australia are also given.

Coinage of completely new design struck at the Royal Mint during 1958 included the following series of coins for Ghana: cupro-nickel: 2s., 1s., 6d., 3d.; bronze: 1d., ½d. These coins, together with others and with the medals and seals struck during the year, are illustrated.

In his report the Comptroller puts the case for and against decimalisation of the coinage, and discusses suggested coinage reforms centred on the withdrawal of the farthing, the size of the penny, the withdrawal of the halfcrown or the florin, and the introduction of a coin, or coins, of higher value than the halfcrown.

Improved Nickel-containing Gunmetals for Quality Castings

MOND NICKEL CO. LTD.: 'Improved Gunmetals for Quality Castings.'

Publication 1885, 1959; 16 pp.

All the standard gunmetals in use to-day have been evolved by trial and error: none of them is capable of providing the ideal combination of properties needed for the production of quality castings. Ideally, a gunmetal should lend itself to easy production in the foundry, and, together with good castability, should exhibit uniformly high mechanical properties and pressure tightness in castings of variable section. This publication reviews the properties of the standard gunmetals most widely used to-day, and describes two improved and competitive alloys developed, as a result of work by The Mond Nickel Company, Ltd., and The International Nickel Company, Inc., to meet the needs of the future. Both the alloys have been evaluated by a number of foundries on a production basis with excellent results, and it has been shown that their use enables a high standard of casting quality to be achieved easily and economically.

One of the alloys covered comprises an improved nickel-containing gunmetal, the compositional limits of which are given as: tin 6–7, zinc 3–5, lead 3–5, nickel 1·5–2·5, total impurities 0·5 max., per cent., copper remainder. The phosphorus content should not exceed 0·02 per cent. in castings over 1 in. (2·5 cm.) in section. This alloy has stable and much higher mechanical properties, at both atmospheric and elevated temperatures, than the widely used 85-5-5-5 gunmetal, but still retains the same adaptability to the production of pressure-tight castings. Castings made to this modified composition are far less sensitive to the effect of casting section than the standard gunmetals, and, when properly made, should have a 0·1 per cent. proof stress in the region of 8 t.s.i. (12·5 kg./mm.^{2}; 17,900 p.s.i.), with a maximum stress of 16–17 t.s.i. (25–26·5 kg./mm.^{2}; 35,800–38,000 p.s.i.) in sections up to 2 in. (5 cm.) thick. The mechanical properties can moreover now be related to those obtained from separately cast test bars. It follows, therefore, that the use of such an alloy will enable castings to be more effectively designed with regard to the use of thinner sections, and hence could result in a considerable saving in weight and cost. The publication includes data indicating the effect of section thickness and design on the mechanical properties of fully-fed sand castings in the improved leaded gunmetal and the standard 88-10-2 and 85-5-5-5 alloys. Casting production, costs and applications are discussed.

The other alloy described represents an improved grade of 'Ni-Vee' Type A gunmetal, and falls within the following composition range: tin 6–7, nickel 5–5·5, zinc 1·5–2·5, lead 0·1–0·5, per cent., remainder copper. Percentage maxima laid down for impurities are as follows: iron 0·25, manganese 0·2, antimony 0·15, aluminium 0·01, silicon 0·01, others 0·25.

The original Type A gunmetal (based on the composition copper 88, tin 5, nickel 5, zinc 2, per cent.) was developed by The International Nickel Company, Inc. The alloy is age-hardenable, and has been used in America for the production of cast components where high mechanical properties are required in conjunction with improved resistance to wear and corrosion (e.g., gear wheels, bearings, valve bodies, actuating nuts, etc.). With this basis composition, however, small additions of lead (up to 0·1 per cent.), which inhibit age-hardening and also promote quench cracking, have given rise to production difficulties.

Recent investigations conducted by The British Non-Ferrous Metals Research Association have shown that a slight modification in the nickel/tin ratio, to increase the rate of ageing, would counteract the inhibiting effect of lead, and that cracking could be avoided by omitting the quenching operation during the heat-treatment. The mechanical properties of an alloy containing tin 6–7, nickel 5–5·5, zinc 1·5–2·5, lead 0·1–0·5, per cent., balance copper, will fall within the following range (after heat-treatment consisting of 2 hours at 780–800°C., air-cool, 6 hours at 315–325°C., air-cool):

	t.s.i.	kg./mm.^{2}	p.s.i.
0·1 per cent. proof stress	15–27	23·5–42·5	33,600–60,500
Maximum stress	25–33	39·5–52	56,000–73,900
Elongation		25–5 per cent.	
Hardness		120–200 B.H.N.	

These results are associated with the other properties of 'Ni-Vee' Type A previously mentioned, and the castings are less sensitive to the effect of casting section. It should be noted, however, that the alloy is age-hardenable and is not therefore recommended for use at elevated temperatures.

Details are given of the influence of section thickness on the mechanical properties of such castings, and casting production and applications are discussed.

Age-Hardening and Tensile Properties of Nickel-Tin-Bronze Sand Castings

J. E. BOWERS and B. S. MUNRO: 'The Mechanical Properties of Heat-Treated Nickel-Tin-Bronze Sand Castings and the Effect of Impurities, especially Lead.'

British Foundryman, 1959, vol. 52, Oct., pp. 425–35.

The investigation described was undertaken to obtain data on the ageing behaviour and mechanical properties of twelve sand-cast alloys containing nickel 2–10, tin 2–10, zinc 2, per cent., remainder copper. The influence of lead (which has been reported in the literature to inhibit age-hardening), aluminium and silicon was also studied.

Solution-treatment was at 760°C., or at the minimum temperature above 760°C. which would produce a single-phase structure in 16 hours. The ageing process (at temperatures in the range 150°–400°C.) was investigated by microscopical examination and

hardness determinations, and subsequently cast tensile specimens were heat-treated to give a range of properties which would permit comparison of the alloys studied. In experiments to determine the influence of impurities on mechanical properties and rate of age-hardening, part of each melt was cast as a control sample, and 0·1 per cent. of lead, silicon or aluminium was then stirred into the remainder before casting. The effect of lead on one of the alloys (containing nickel 5, tin 5, zinc 2, per cent.) was further studied by making successive additions to the melt, in amounts up to 14 per cent., so that the copper : nickel : tin ratio was maintained constant. The data obtained from the investigation are presented *in extenso*.

The alloys within the system studied were found to be heat-treatable to a high hardness. Ageing behaviour at high temperatures was typical, the strength increasing and ductility decreasing with ageing time. The authors summarise their main findings as follows:

'(1) Given a suitable heat-treatment, a useful combination of strength and ductility can be obtained from these alloys, with the exception of those containing 8–10 per cent. of both nickel and tin, which tend to be brittle. The 4 per cent. nickel–10 per cent. tin alloy studied was also brittle in the as-cast state but had slightly enhanced ductility after solution-treatment, when aged to a tensile strength less than 30 t.s.i. (47·25 kg./mm.^{2}; 67,200 p.s.i.).

'(2) 0·1 per cent. lead slows down the age-hardening process and reduces the ductility obtained at any specified tensile strength. The reduction is not large, however, and the properties are not unduly impaired even when lead is present. Silicon and aluminium as impurities are deleterious at the 0·1 per cent. level.

'(3) An excess of tin over the 1 : 1 ratio of nickel: tin is preferred, since any variation of tin, within the specification, will then have little effect on the rate of ageing of the alloy; for example, an alloy containing 5–5½ per cent. of nickel with 6–7 per cent. of tin and 2 per cent. of zinc should give useful properties and have a reasonable ageing rate even with 0·1–0·2 per cent. of lead.'

Polishing and Buffing of Nickel-containing Materials

See abstract on p. 376.

NICKEL-IRON ALLOYS

Magnetic Properties of Metals and Alloys

AMER. SOC. METALS: 'Magnetic Properties of Metals and Alloys.'

Published by the Society, 1959; 329 pp. + appendices and index.

This volume contains the papers presented at a Seminar on Magnetic Properties of Metals and Alloys held during the National Metal Congress and Exposition, Cleveland, October 1958.

The papers (see below) are concerned both with practical developments in the field of magnetic materials (e.g., the study of thin films and the construction of permanent magnets from fine particles) and with work directed primarily towards the understanding of magnetic phenomena, but, in either case, much of the illustrative data relate to nickel or nickel-containing materials.

J. H. VAN VLECK: 'Fundamental Questions in Magnetism', pp. 1–17.

C. P. BEAN and R. W. DeBLOIS: 'Experimental Measurement of Fundamental Magnetic Properties', pp. 18–34.

H. J. WILLIAMS and R. C. SHERWOOD: 'Magnetic Domain Structures', pp. 35–55.

R. G. SHULMAN: 'Nuclear Magnetic Resonance in Magnetic Crystals', pp. 56–67.

J. J. BECKER: 'Metallurgical Structure and Magnetic Properties', pp. 68–92.

J. E. GOLDMAN and A. ARROTT: 'Magnetic Measurements in Metallurgy', pp. 93–111.

J. B. GOODENOUGH and D. O. SMITH: 'Magnetic Properties of Thin Films', pp. 112–145.

T. O. PAINE: 'Magnetic Properties of Fine Particles', pp. 146–67.

G. W. RATHENAU: 'Time Effects in Magnetisation', pp. 168–99.

W. J. CARR: 'Magnetostriction', pp. 200–50.

A. COCHARDT: 'Magnetomechanical Damping', pp. 251–79.

B. L. AVERBACH: 'Spin Clusters in Iron near the Curie Temperature', pp. 280–7.

C. D. GRAHAM: 'Magnetic Annealing', pp. 288–329.

Effects of Temperature on Magnetic-Core Materials

M. PASNAK and R. H. LUNDSTEN: 'Effects of Temperature on Magnetic Core Materials Over the Temperature Range 24°–850°C.'

Electrical Manufacturing, 1959, vol. 64, Oct., pp. 119–26.

The investigation, in which most of the important commercially available magnetic alloys were evaluated, was initiated, in view of military demands for components suitable for applications involving extremes of temperature, to provide information for the design engineer and for future development work.

Thirty specimens, representing twelve grades of magnetic alloy, were tested. The results obtained for the following ten alloys are reported in the present paper (the properties and behaviour of the remaining two, 'Z-Silectron' and 'Audio Transformer-A', being closely similar to those of 'L-Silectron' and 'Transformer-A', were omitted): Silicon-iron alloys: 'L-Silectron' (grain-oriented), 'Transformer-A' (non-oriented); Aluminium-iron alloys: '11·7 Alfenol' (ordered), '15·5 Alfenol' (disordered), '3 Mo Thermenol'; Vanadium-cobalt-iron alloy: 'Supermendur';

Cobalt-nickel-iron alloy: '7-70 Perminvar'; Nickel-iron alloys: 'Orthonol' (grain-oriented), 'AEM 4750' (non-oriented), '4-79 Mo Permalloy'.

The study was conducted in two stages. In the first, the magnetic properties of all the materials were determined (1) at temperatures ranging (at intervals of 100C.°) from 24° to 500°C. or to the Curie point, whichever was the lower, and (2) during temperature cycling between 24° and 500°C., using two cooling rates. In the second phase, specimens of those materials with Curie points above 500°C. were tested from 24° to 500°C. and then, at intervals of 100C.°, up to a temperature in excess of the Curie point; each was then cooled at a controlled rate and re-tested at 24°C. The total soaking time at any temperature was two hours: one hour to permit stabilisation, the other for testing.

Data on the A.-C. and D.-C. magnetic properties are presented in a series of tables, and the paper includes the D.-C. induction (virgin-magnetisation) curves determined for each test temperature. The characteristics of each material are summarised in the text.

With rise in temperature most of the materials studied exhibited the normal characteristics of decreasing saturation induction, residual induction and coercive force, but the grain-oriented materials were more affected by temperature cycling than the unoriented materials. The effects of temperature cycling were, in general, reflected in an increase in the coercive force, a decrease in the maximum permeability, a decrease in the residual flux density, and a decrease in the squareness ratio with each temperature cycle.

The magnetic properties of 'Supermendur', '7-70 Perminvar', and the aluminium-iron alloys were found to be critically dependent upon the cooling rates to which they were subjected.

The silicon-iron materials were prone to severe oxidation when exposed to air at elevated temperatures, and this tendency indicates the advantage of hermetically sealing them in an atmosphere of inert gas or *in vacuo*.

Magnetic Annealing in Iron-Cobalt-Nickel Alloys

'Magnetic Annealing in Perminvar.'

R. D. HEIDENREICH, E. A. NESBITT and R. D. BURBANK: 'I. Structure and Origin.'

Jnl. Applied Physics, 1959, vol. 30, July, pp. 995-1000.

E. A. NESBITT and R. D. HEIDENREICH: 'II. Magnetic Properties.'

Ibid., pp. 1000-3.

The experiments reported were conducted in an attempt to explain, on the basis of an observed structural rearrangement with field heat-treatment, the response exhibited by a wide range of soft, magnetic alloys to magnetic annealing.

Part I of the paper gives details of an electron-diffraction study of the structure of iron-cobalt-nickel alloys which exhibit magnetic annealing. In the experiments described in Part II these structural findings were correlated with the magnetic properties of the alloys.

The results show that response to heat-treatment in a magnetic field is dependent upon the oxygen present in the alloy as an impurity, and is associated with distinct diffraction phenomena. A structural model is presented based on a correlation of the diffraction results, magnetic properties and oxygen content.

An oxygen content of about 0·001 per cent. was found to be sufficient to produce magnetic annealing with proper heat-treatment, but an alloy containing only 0·0001 per cent. oxygen failed to respond to field heat-treatment. With appropriate heat treatment the oxygen impurity produces magnetic activity in the alloy crystal by condensing into the (111) planes of the crystal, giving rise to a stacking disorder or fault. (The term 'impurity fault' is introduced to describe this structural irregularity.) The oxygen impurity faults are thought to be aligned by magnetic annealing, and are intimately connected with field heat-treatment properties. If sufficient oxygen is available in the crystal, the faults thicken and organise to yield metal oxides.

CAST IRON

Use of 'Ni-Hard' for Grinding-Mill Liners

W. H. ZIEMAN: 'Forum on Ball and Rod Mill Liners.'

Canadian Mining and Metallurgical Bulletin, 1959, vol. 52, Aug., pp. 511-28.

This paper reviews the proceedings of the third of the Annual Forums on Grinding instituted, under the auspices of the Canadian Mining and Metallurgical Society, in 1957. Discussion at the previous forums had indicated that one of the most important factors which influence grinding efficiency is the design of the mill liners, and, to throw light on the types of liner at present in use in Canada, it was decided to submit questionnaires to the industry requesting tabular data on routine practice which, wherever possible, were to be supplemented by comments on any points of interest applicable to the particular plant. Thirty-seven companies responded to this request, and the data obtained formed the basis for discussion at the 1959 Annual Forum.

The proceedings are reviewed in three sections. In the first the information compiled from the questionnaires is summarised in tabular form, and reference is made to contributors' remarks dealing with points of specific interest. The data submitted by each of the thirty-seven firms, classified in thirty-four columns, cover virtually every factor associated with service conditions and performance of the liner (e.g., plant capacity, stage, type of mill (rod, ball or pebble), dimensions of the liner, materials of construction of liner, grinding media, etc.). The liner materials to which the data relate are white iron, manganese and chromium-molybdenum steels, and the nickel-chromium white cast iron 'Ni-Hard'. Grinding balls were in white iron, forged steel, cast steel or 'Ni-Hard'.

In section II an analysis is made of the data tabulated in the first section. Reference is made, *inter alia*, to the decided preference shown for 'Ni-Hard' as a liner material. Manganese steel is, however, still employed when toughness is required, and chromium steel where toughness is necessary and peening cannot be tolerated. White iron is considered capable of competing on an economical basis with 'Ni-Hard' when used for pocket or smooth liners.

Section III of the paper reports the discussion which followed the presentation of the data.

CONSTRUCTIONAL STEELS

Investment Castings in Carbon- and Low-Alloy Steel: British Standard

BRIT. STANDARDS INSTN.: 'Investment Castings in Metal. Part 1. Carbon- and Low-Alloy Steels.'
B.S. 3146: Part 1: 1959; 26 pp. Price 6/-.

The Standard lays down requirements for investment castings in the following types of steel: carbon steel; 1½ per cent. manganese steel; alloy steels with tensile strengths in the ranges 45–55 and 55–65 t.s.i.; high-tensile steel; carbon-molybdenum steel; 3 per cent. chromium-molybdenum steel; carbon-steel for surface hardening; carbon case-hardening steel; 3 per cent. nickel case-hardening steel; 3 per cent. chromium-molybdenum nitriding steel; 1 per cent. chromium abrasion-resisting steel.

Section I of the Standard specifies general requirements with respect to the manufacturing process, composition, fettling and dressing, heat-treatment, methods of testing, etc. Section II outlines the compositional limits, heat-treatment and mechanical properties laid down for each of the grades of steel covered.

The following composition range is given for castings in the nickel case-hardening steel: carbon 0·1–0·18, silicon 0·25–0·6, manganese 0·3–0·6, sulphur 0·05 max., phosphorus 0·05 max., chromium 0·3 max., molybdenum 0·15 max., copper 0·3 max., nickel 2·75–3·5, per cent.

Temper-Embrittlement: Literature Review

T. P. SINGH: 'Temper-Embrittlement: A Review of the Literature.'
Metal Treatment, 1959, vol. 26, July/Aug., pp. 275–83.

In this critical review of published work on temper-embrittlement in steels the author discusses literature (the *bibliography* contains 37 items) relating to: the mechanical and metallographic techniques used to evaluate embrittlement characteristics; the mode of fracture in embrittled and unembrittled steels; the effects of temper-embrittlement on the properties of the steel; the isothermal kinetics involved in embrittlement; the susceptibility to embrittlement of various grades of nickel-containing steels; the influence of microstructure and grain-size; and temper-brittleness in plain-carbon steels.

Internal Friction and Temper Brittleness in Low-Alloy Steel

A.-F. K. KADDOU and P. C. ROSENTHAL: 'Correlation Between Internal Friction and Temper Brittleness in Steel.'
Amer. Soc. Metals, 1959, *Preprint* 151; 12 pp.

Research by other workers having established that carbon atoms play a predominant rôle in promoting temper brittleness in steels, the investigation now reported was carried out to determine, by means of internal-friction studies, the influence of carbon on the occurrence of temper brittleness in two steels, a low alloy nickel-chromium steel (A.I.S.I. E 3310) and a carbon steel (A.I.S.I. C 1016), the former being highly susceptible, and the latter insensitive, to embrittlement.

Some of the specimens studied were subjected to an embrittling, and the remainder to a non-embrittling, heat-treatment. The internal friction of the specimens studied was measured, at temperatures ranging from room temperature to 500°F. (260°C.), using a torsional pendulum at a frequency of 1–5 cycles/sec. The results of this study were supplemented by data derived from Charpy impact tests.

On the basis of the data obtained, the authors interpret the mechanism of temper brittleness in terms of the segregation of solute atoms to the dislocations at the grain boundaries and in the crystal lattice, forming a Cottrell-type atmosphere: the type of dislocation atmosphere determines whether the steel is tough or temper-embrittled. The data suggest that temper brittleness is not a grain-boundary phenomenon but a state in which all the dislocations which contribute to plastic flow are anchored rigidly by the condensed atmospheres. Under certain conditions of strain rate and test temperature, these dislocations cannot contribute to the plastic flow and hence intergranular failure results.

Elevated-Temperature Properties of Cast and Wrought High-Strength Steels

R. K. BUHR and W. A. MORGAN: 'Cast and Wrought Alloy Steels: Elevated-Temperature Properties.'
Modern Castings, 1959, vol. 36, Oct., pp. 61–7.

Whilst a great deal of information is available on the properties of high-strength steels in the wrought condition, the properties of similar grades of steel in the cast condition have not been investigated so extensively. In the work now reported the authors have compared the high-temperature properties of cast and wrought specimens obtained from the same heats of low-alloy steel.

A nickel-chromium-molybdenum steel and three grades of chromium-molybdenum-vanadium steel were selected for study. Tensile properties were determined at 70°, 700° and 1000°F. (20°, 370° and 540°C.), and Charpy V-notch impact tests

were conducted at room temperature and −40°F. (−40°C.). Fatigue properties were determined on notched and unnotched specimens. Experiments were carried out to establish optimum tempering temperatures and the mechanism involved in secondary hardening was also investigated. Full details are given of the procedures used and the data obtained.

These data indicate that, in the cast condition, the steels offer advantages that render them suitable for service at elevated temperatures. Although their room-temperature ductility was somewhat inferior to that of wrought specimens, this difference became very much less marked at high temperatures. The fatigue properties of unnotched specimens were higher for the wrought steels, but in the wrought condition the steels were found to be much more notch-sensitive than in the cast. A further advantage of the cast steels is that their properties are not influenced by directionality effects.

Investigation of the mechanism of secondary-hardening, using electron microscopy and electrolytic carbide-extraction techniques, verified that the strengthening effect was due to precipitation of fine alloy carbides.

Influence of Structural Variables on the Properties of High-Strength Cast Steel

M. C. FLEMINGS, R. GREEN and H. F. TAYLOR: 'Structural Variables Influencing Mechanical Properties of High-Strength Cast Steels.'

Modern Castings, 1959, vol. 36, Oct., pp. 84–98.

Many of the problems encountered in the production of castings in high-strength steel (e.g., hot tearing, shrinkage defects, surface defects, segregation of non-metallic and alloying elements) are associated with the solidification mechanism of the steel, and should therefore be overcome or minimised by appropriate control of the mode of solidification and of such factors as melt composition, melting practice and heat-treatment. The present paper describes the initial phase of an investigation of the effect of solidification variables on the structural properties of high-strength cast steels.

Plate specimens of a low-alloy nickel-chromium-molybdenum steel (a modification of the A.I.S.I. 4330 grade) were cast, in different moulding materials, to obtain widely varying conditions of solidification. Cooling rates during solidification were varied (at test-bar locations) from 300F.° (165C.°) to less than 20F°. (10C.°) per minute, and the thermal gradients from 350F.° (195C.°) to less than 70F.° (40C.°) per inch.

The differences in solidification conditions did not significantly influence the macrostructure (columnar, original austenite grains), but affected the microstructure in important ways. With increase in the cooling rate, the internal structure of the dendrites became much finer and the inclusions finer and more evenly distsibuted. Slow cooling rates tended to result in coarser agglomerated inclusions. Voids (microporosity) were evident in the central portion of all the plates, and were most marked in an unchilled casting poured in dry sand.

Tensile and impact properties were determined for various locations of quenched and tempered plates solidified under different thermal conditions. Tensile and yield strengths were essentially constant in all the plates, but large variations, depending on solidification conditions, were obtained in elongation and reduction-in-area. These variations were attributed to differences in microporosity, micro-segregation, and size and distribution of inclusions.

The effects of extremely high solidification rates were studied in a brief investigation of the structure and properties of metal melted by arc welding and then allowed rapidly to resolidify.

Influence of Small Forging Reductions on the Properties of Nickel-Chromium-Molybdenum Steel

H. J. WAGNER and J. W. SPRETNAK: 'The Effect of Initial Increments of Hot Working on the Mechanical Properties of Certain Ferrous Materials.'

Amer. Soc. Metals, 1959, *Preprint* 170; 17 pp.

One of the methods suggested for reducing the intermediate operations involved in hot forging components of complex shape is to cast a blank approximating to the final shape, which would then be lightly forged to obtain the required mechanical properties. The success of this procedure would, however, depend on the degree to which the properties would be achieved by relatively small reductions, and the work reported by the authors was carried out with the aim of obtaining the relevant information.

In studying the relationship between the forging ratio and the mechanical properties obtained, it was considered advisable to take into account the influence of inclusions and chemical heterogeneity. The tests were therefore conducted on castings produced from two heats of iron and two heats of low-alloy nickel - chromium - molybdenum steel (A.I.S.I. 4340), one heat of each material containing a high, the other a low, level of sulphide inclusion.

All hot working was accomplished by slow upset forging in a hydraulic press. Preliminary tests having shown that the degree of deformation varied from point to point in the forging, a method of determining this variation was developed (and is described) which permitted a more accurate correlation with mechanical properties. Tensile specimens were removed from the forged billets in both the radial and axial directions.

On the basis of the findings quoted below, the authors conclude that forging of rough-cast blanks might indeed be a practicable method of reducing the number of press operations involved in fabricating castings of normal soundness.

'(1) Tensile strengths of iron and A.I.S.I. 4340-type steel were not affected by upset forging to height ratios up to 2·1, implying that chemical heterogeneity does not influence the independence of tensile strength and degree of forging.

'(2) The tensile strength was independent of the degree of upset forging to height ratios up to 2·1,

for both high- and low-sulphur contents, in both iron and A.I.S.I. 4340 steel.

'(3) The minimum ductility at a particular degree of forging was usually in the axial direction. For both iron and A.I.S.I. 4340 steel, forging to a height ratio greater than 1·4 either lowered or had little effect on the ductility in the axial direction.

'(4) Forging to a height ratio of 2·1 resulted in a greater difference between ductility in the axial and in the radial directions than forging to a height ratio of only 1·4. The presence of sulphide inclusions increased the degree of directionality.

'(5) Increased amounts of forging showed a tendency toward increasing the limits of expected values of ductility. A minimum in the limits seemed to occur at a height ratio of 1·4.'

Control of Austenitic Grain-Size in Medium-Carbon and Carburising Steels

B. L. BIGGS: 'Austenitic Grain-Size Control of Medium Carbon and Carburising Steels.'

Jnl. Iron and Steel Inst., 1959, vol. 192, Aug., pp. 361–77.

This paper is concerned with the control of austenitic grain-size in heat-treated wrought steels and does not cover as-cast materials.

The review is in two sections. In the first the techniques employed for grain-size control of medium-carbon and carburising steels produced by the acid open-hearth, basic open-hearth and basic electric processes are discussed, and reference is made to critical factors which influence the recovery of acid-soluble aluminium in the steel. Methods for rapid assessment of grain-size are considered, and data are presented correlating grain-size (as determined by the McQuaid-Ehn test) with the total aluminium content of basic open-hearth steel of the following types: En 34 (nickel-molybdenum carburising steel), En 8M (medium-carbon free-cutting steel), En 18 (medium-carbon 1 per cent. chromium steel) and En 361 (chromium-nickel-molybdenum carburising steel). Of these four steels, the En 34 grade is considered to be by far the most easily controlled, since it requires the lowest residual aluminium content and also attains the smallest mean grain-size. The curve given indicates a very slight tendency towards a reversion to grain coarsening when the total aluminium content exceeds about 0·02 per cent. The En 361 steel was the most difficult to control, and required the highest residual content. With suitable residual aluminium contents, however, the grain-size can be controlled to a fineness similar to that achieved with the En 8M and En 18 grades. A slight reversion to grain-coarsening is indicated when the total aluminium content exceeds about 0·035 per cent.

The influence, on grain-size, of the variables involved in steel-making is discussed in relation to data indicating the relationship between aluminium recovery (in steels produced by the basic electric-arc and basic open-hearth processes) and the amount of the aluminium addition, the method by which the addition was made, and the carbon and silicon contents of the steel. A survey is made of various theories advanced in explanation of the mechanism of grain-size control, and the section ends with reference to experimental work carried out in this connection by Hadfields, Ltd.

The second section of the paper (the data supplementing which relate mainly to steels of En 18 grade) is concerned with the factors governing the incidence of ingot cracking in medium-carbon steels with grain-sizes controlled by aluminium additions. Methods of combatting the problem are discussed.

Development, Properties and Applications of Basic Low-Hydrogen Electrodes

D. C. SMITH: 'Development, Properties and Usability of Low-Hydrogen Electrodes.'

Welding Jnl., 1959, vol. 38, Sept., pp. 377s–92s.

Of the two types of covering which form the basis of those used in commercially available electrodes, the mineral type originated in Europe and the organic was developed in the U.S.A. The mineral covering may be sub-divided into the acid- and basic-slag types, and the low-hydrogen version of the latter type, which was developed in the U.S.A. during and since the end of the last war, has contributed to the development of electrodes capable of producing sound welds in high-tensile and other steels previously regarded as difficult or impossible to weld. In this report, which was sponsored by the Welding Research Council and is based on a *bibliography* of 17 items, the author reviews the development, properties and applications of low-hydrogen electrodes, with the aim of indicating the factors which must be taken into account if optimum results are to be obtained from their use.

Typical covering and slag compositions are tabulated for commercial electrodes representative of organic and mineral types, and, as a means of throwing light on the superior qualities of basic low-hydrogen electrodes, as compared with conventional acid-slag types, the author briefly discusses the function of an electrode covering. The development of low-hydrogen electrodes suitable for welding ultra-high-strength steels is then reviewed, in some detail, in sections relating to low-tensile electrodes, high-tensile electrodes, and the effects of adding iron powder to the coatings.

The modifications in welding technique necessitated by use of low-hydrogen electrodes are outlined, and the function and control of the slags are discussed. In subsequent sections the author's evaluation of the properties of mild-steel, high-tensile-steel and ultra-high-tensile-steel low-hydrogen electrodes is supported by reference to numerous tabular and graphical data (much of which relates to nickel-chromium-molybdenum low-alloy-steel weld metal) and to the compositional and property requirements laid down in U.S. military specifications for chromium-molybdenum and nickel-chromium-molybdenum low-alloy-steel electrodes.

The influence of hydrogen on weld-metal cracking

and cold cracking in the heat-affected zone is discussed, and findings are summarised with respect to the detrimental effects, on the weldment, of moisture present in the covering of low-hydrogen mild-steel and low-alloy-steel electrodes. Reference is made to the care and storage of the electrodes and, in the final section of the paper, the author briefly reviews the main fields in which advantage is taken of their ability (*a*) to weld free-machining steels without porosity and weld cracking, (*b*) to weld severely-air-hardened steels without the formation of underbead cracking, even when not pre-heated, (*c*) to allow the introduction of carbon and of ferro alloys of silicon, manganese, chromium, vanadium, etc., without deleterious effects on performance characteristics.

HEAT- AND CORROSION-RESISTING MATERIALS

Symposium on High-Temperature Materials

'High-Temperature Materials.'
Edited by R. F. HEHEMANN and G. M. AULT.
Published by *John Wiley and Sons, Inc.*, New York, 1959; *Chapman and Hall, Ltd.*, London; 544 pp. Price 140/-; $17·50.

A Symposium on recent developments in high-temperature materials, sponsored by the High-Temperature Materials Committee of the American Institute of Mining, Metallurgical and Petroleum Engineers, was held in Cleveland, April 1957. In view of the interest aroused by the Symposium it was decided to publish the proceedings in the form of the present book. The 34 papers are classified, according to subject matter, in seven sections. Sections I and II review the characteristics of nickel- and cobalt-base alloys and of cermets, and discuss the factors governing the performance of these materials at high temperatures. The refractory metals, which offer promise of development for service at temperatures above 2000°F. (1095°C.), are discussed in Section III, while dispersion-hardening and dispersion-hardened materials form the subjects of Section IV. Sections V, VI and VII are concerned with those features of gas/metal interactions which are of fundamental importance in the field of high-temperature alloys: vacuum melting and its beneficial effects on the properties of the alloys produced; the influence of environment on the behaviour of materials at high temperatures; and the oxidation-resistance of high-temperature alloys.

The scope of the individual papers is indicated in the abstracts below.

I. *Cobalt- and Nickel-base Alloys*

Status and Future of Nickel-base Alloys

F. L. VERSNYDER: 'Status and Future of Nickel-base Alloys', pp. 3–15.

The author briefly reviews the development of heat-resisting nickel-base alloys since the introduction of the nickel-chromium alloy 'Nichrome' in 1906, and refers to the advances achieved by application of improved processing techniques, particularly vacuum melting and vacuum casting. Notes on the mechanical properties of typical nickel-base alloys are supplemented by data comparing the high-temperature properties of such alloys with those of various other materials, and indicating the stress-rupture characteristics of 'M-252', 'Nimonic 80', 'S-816' and 'Udimet 500'. Structures typical of those observed in nickel-base alloys are discussed, and particulars are given of phases identified in studies of the minor constituents present. Brief reference is made to work on the problem of intergranular fracture.

Influence of Alloying Additions on the Stress-Rupture Properties of Nickel-Chromium-Iron-Cobalt-base Alloys

T. L. ROBERTSHAW: 'Investigation of High-Temperature Properties of Nickel-base Alloys Using Balanced-Experiment Designs', pp. 16–27.

The paper has a twofold purpose: (1) to provide an introduction to the techniques of balanced experimental design, as applied to the development of high-temperature alloys; (2) to present data on alloy systems (of nickel-chromium-iron-cobalt base) which offer promise for service at temperatures in the region of 1750°F. (955°C.).

A fully documented report of the experimental procedures and the results obtained was given by SYE, ROBERTSHAW and RICHMOND in *Wright Air Development Center Report* 57-426. The scope of the investigation and the salient findings are indicated in *Nickel Bulletin*, 1958, vol. 31, No. 11, pp. 295–6.

Suitability of 'Guy Alloy' for Use in Turbine Blades

R. A. SIGNORELLI, J. R. JOHNSTON and J. W. WEETON: 'Evaluation of a Cast Nickel-base Alloy for Use as a Bucket Material at 1650°F.', pp. 28–37.

The authors give details of an investigation designed to determine the suitability of the heat-resisting casting alloy, 'Guy Alloy', for use in turbine blades. (The nominal composition of the alloy is given as: carbon 0·1 max., nickel 64–70, chromium 12–15, molybdenum 5–6, aluminium 5·5–7·0, iron 4·5, niobium 2·0, boron 0·5, manganese 0·5, silicon 0·5, per cent.)

In preliminary studies, as-cast test bars were subjected to tensile tests at room temperature and to stress-rupture tests at 1650° and 1800°F. (900° and 980°C.), and, with a view to throwing light on impact-resistance and the feasibility of using conventional serrated-root fastening, turbine blades were subsequently evaluated in engine tests at 1500°F. (815°C.). From the data so obtained the temperature for the main high-stress engine test, using a full wheel of 'Guy Alloy' blades, was established at 1650°F. (900°C.).

The main test had to be suspended after 102 hours because of damage to the compressor, but in that time no failure occurred in any of the 'Guy Alloy'

blades. 'S-816' blades evaluated at 1500°F. (815°C.) in the same engine exhibited a mean rupture life of 200 hours.

'W-545': Iron-Nickel-Chromium-base High-Temperature Alloy

J. T. BROWN and J. BULINA: ' 'W-545': A New Higher-Temperature Turbine Disk Alloy', pp. 38-55.

The paper describes (1) the research by Westinghouse Electric Corporation which culminated in the development of the iron-nickel-chromium-base high-temperature alloy 'W-545', and (2) the results of the test programme carried out to determine the properties of the alloy. The information presented is closely akin to that given by BROWN in *Metal Progress*, 1958, vol. 74, Aug., pp. 87-90: see abstract in *Nickel Bulletin*, 1958, vol. 31, No. 12, p. 232.

In a footnote to the paper attention is drawn to the improved properties exhibited by 'W-545' when produced by consumable-electrode vacuum arc melting with a cold-hearth mould: see, in this connection, abstract of a paper by the same authors, *Nickel Bulletin*, 1959, vol. 32, No. 11, p. 335.

History, Status and Future of Cobalt-base Alloys

G. A. FRITZLEN: 'History, Status and Future of Cobalt Alloys', pp. 56-80.

The author's main concern is with the presentation of data illustrating the properties offered by cobalt-base alloys and the fields in which the alloys find application.

The paper is introduced by a historical survey of the evolution of cobalt alloys (from the initial researches of Haynes at the turn of the century to work in recent years), by notes on the microstructural features of the alloys which contribute to such properties as their excellent erosion- and heat-resistance, and by a discussion of the future industrial and military potential of the materials. In reviewing the properties of cobalt-base alloys the author refers to data indicating short-time tensile, stress-rupture, thermal-shock, elevated-temperature fatigue and impact, and compressive creep characteristics of such typical cobalt-base and competitive materials as 'HS-21', 'HS-31', 'GMR-235', 'S-816', 'HS-1049', 'M-252', '19-9 DL', 'Hastelloy X', 'Inconel 700', 'Udimet 500', 'Nimonic 90', 'Guy Alloy'.

Properties of 'ML-1700' Cobalt-base Casting Alloy

R. J. MORRIS: ' 'ML-1700' Gas-Turbine Bucket Alloy', pp. 81-94.

Preliminary work carried out, by the General Electric Company, with the aim of developing a cast cobalt-base turbine-blading alloy for use at temperatures in the region of 1700°F. (925°C.), showed that modification of the carbon and boron, and elimination of the nickel, contents of 'HE-1049' alloy produced a material, designated 'ML-1700', possessing an optimum combination of strength and ductility. The present paper reviews the results of a comprehensive test programme which was initiated to evaluate the physical and mechanical properties of this alloy (nominal composition: chromium 25, tungsten 15, carbon 0·2, boron 0·4, per cent., remainder cobalt).

The influence of boron additions on the structure and properties of the alloy is discussed and data are given on stress-rupture and room- and elevated-temperature tensile and impact properties. A wheel of 96 blades was subjected to engine testing at 1700°F. (925°C.) for 115 hours without tensile-, rupture- or fatigue-type failure, but creep-strength proved unsatisfactory. Work involving compositional modifications and use of vacuum melting and new casting techniques is continuing.

Temperature Dependence of Secondary Phases in High-Temperature Alloys

J. H. WESTBROOK: 'Temperature Dependence of the Hardness of Secondary Phases Common in Turbine Bucket Alloys', pp. 95-115.

As a contribution to the understanding of the mechanisms by which secondary phases enhance the properties of high-temperature alloys, the author carried out experiments aimed at determining the temperature-dependence of the hardness of representative phases which have been found in various alloys. The scope of the investigation, which has been previously reported in *Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1957, vol. 209, pp. 898-90, was indicated in *Nickel Bulletin*, 1957, vol. 30, No. 10, p. 184.

II. *Cermets and Intermetallics*

Cermets and Bonded Hard Metals

J. T. NORTON: 'Cermets and Bonded Hard Metals', pp. 119-24.

The paper comprises a general review of the problems which have to be overcome before full advantage can be taken of the potential offered by cermets and bonded hard metals in the high-temperature field. Three factors are discussed: the mechanical properties of the constituent elements of such materials, the microstructure associated with optimum properties, and the means available for obtaining such a microstructure.

Sintered Nickel/Titanium-Carbide Compositions

J. WAMBOLD and J. C. REDMOND: 'Recent Developments in Sintered Titanium-Carbide Compositions', pp. 125-39.

The paper 'describes the methods used for elevated-temperature testing in tension at the Kennametal Laboratory, and points out some of the advances that have been made in (1) testing methods, (2) high-temperature high-strength compositions, and

(3) fabrication techniques pertaining to cemented carbide compositions'.

Details are given of resistance-heated rupture specimens used for determination of high-temperature properties, and of ballistic-impact-testing equipment, results obtained by the latter equipment being correlated with those derived from standard Charpy impact tests. The paper also contains illustrations of turbine components and bearings made from sintered titanium-carbide compositions. Much of the data presented relate to nickel-containing compositions (e.g., 'K-152B', 'K-162B' 'K-164B', 'K-183A' and 'K-196' grades of the 'Kentanium' nickel/titanium-carbide series).

Titanium-Carbide Compositions Infiltrated with High-Temperature Alloys

H. W. LAVENDEL and C. G. GOETZEL: 'Recent Advances in Infiltrated Titanium Carbides', pp. 140–54.

The considerable amount of work which has been carried out to strengthen nickel-base 'superalloys' by the introduction of a substantial quantity of titanium carbide has met with some success (the dispersion of the hardening phase being achieved by infiltrating the alloy into an accurately shaped titanium-carbide skeleton), and several grades of material (e.g., 'SCA-100') have been produced in the form of turbine blades and nozzle vanes. In the search for improved materials, the experience gained in developing the nickel-alloy/TiC compositions has now been applied to an investigation of the cobalt-alloy/TiC system. An indication of the results obtained is given in the present paper.

The following features of the study are discussed: the infiltration technique, typical microstructures observed in the Co-alloy/TiC compositions, high-temperature properties and impact-resistance.

The paper includes a description of the development of graded and clad cermets, as exemplified by nickel-alloy-infiltrated titanium-carbide compositions clad with a ductile nickel alloy. (A graded and clad cermet is one which is clad with a ductile material and in which the metal-binder content changes along selected directions so as to improve, without depreciation in the intrinsic strength of the core of the body, the ductility of surface layers, trailing and leading edges and airfoil tips and roots.)

Wettability and Microstructural Studies in Liquid-Phase Sintering of Nickel-containing Materials

N. M. PARIKH and M. HUMENIK: 'Wettability and Microstructure Studies in Liquid-Phase Sintering', pp. 155–68.

Sintering in the presence of a liquid phase is an important phenomenon involved in the densification of a large variety of systems, including metal, ceramic and cermet. In this paper the author discusses the general theoretical principles pertaining to liquid-phase sintering and re-examines the 'heavy-alloy' theory (which suggests that densification, and the resultant microstructures, are determined by solution of the solid in the liquid at sintering temperature and subsequent reprecipitation) in the light of data derived from experimental work on compacts representative of the following systems: WC/Cu, WC/Co, TiC/Ni, TiC/NiMo, Ni/$Na_2O \cdot 2SiO_2$ glass, and tungsten-copper. Contact angles were determined in wettability studies, and the microstructures of the compacts were examined, after sintering and cooling, in relation to the 'heavy-alloy' concept.

The results show that although solubility of the solid in the liquid may be very important in controlling the rate of densification, and probably also the shape of grains, its effect on the distribution of the various phases present in multi-phase heterogeneous systems is of minor significance. They indicate also that the microstructures and the distribution of the various phases are determined primarily by the relative surface energies of different interfaces. A general concept (the 'coalescence hypothesis') is presented based on these findings.

Fracture and Slip in Nickel-containing Cemented Carbides

N. M. PARIKH: 'Modes of Fracture and Slip in Cemented Carbides', pp. 169–81.

The investigation described comprised an extension of that referred to in the preceding abstract. Modes of fracture in WC/Cu, WC/Co, TiC/Ni and TiC/NiMo systems were studied by subjecting specimens produced by conventional powder-metallurgy techniques (involving sintering in the presence of a liquid phase) to a 100-kg. load, using a Rockwell hardness-testing machine. The mode of fracture was determined by metallographic examination.

It is concluded from the data presented that the modes of fracture in cemented carbides are governed by the microstructures, which, in their turn, are influenced by relative surface energies. Systems, such as TiC/Ni or WC/Cu, which show partial wettability of the solid phase and are characterised by formation of coalesced carbide grains, fail by transgranular fracture, while systems (e.g., WC/Co or TiC/NiMo) which are completely dispersed owing to complete wettability of the solid phase exhibit interfacial fracture. In dispersed systems a critical film thickness is observed, and at this point the energy imparted is absorbed in the creation of slip bands rather than in fracture. The particle size of the carbide in a dispersed system was found to have a profound influence on the modes of fracture, the path of fracture changing from the binder to transgranular (carbide) at some particle size in the region of 2–4 microns.

High-Temperature Materials Based on Intermetallic Compounds

R. STEINITZ: 'Materials Based on Intermetallic Compounds', pp. 182–9.

The study reported was conducted to gain a preliminary assessment of the feasibility of using inter-

metallic compounds as a basis for development of high-temperature alloys. For the most part only materials with a melting point above 1500°F. (815°C.) were studied, and satisfactory oxidation-resistance was a prerequisite for further investigation of those initially selected.

The intermetallic systems discussed are those of transition metals with silicon or aluminium, or those formed between any two of the following transition metals (the compounds formed by which, and the author's assessment of their potential, are noted in tabular form): nickel, cobalt, iron, manganese, chromium, vanadium, titanium, silicon, tantalum, molybdenum, niobium, zirconium.

Special attention is devoted to the Ni-Al-Ti and Ni-Al systems, and, though none of the materials studied was found to be superior in its general behaviour to standard carbide or boride cermets, the Ni-Al-Ti system is considered worthy of further investigation, and the properties of some of the compounds (e.g., nickel aluminide and molybdenum disilicide) render them of interest in fields other than the high-temperature.

Evaluation of Nickel-containing Cermet Turbine Blades

G. C. DEUTSCH: 'The Use of Cermets as Gas-Turbine Blading', pp. 190–204.

The author discusses data derived from engine tests on cermet turbine blades in terms of the problems revealed by the test programme, the solutions achieved for some of these problems, and the problems that remain to be overcome.

The blades studied were fabricated from 'K-152B' 'a composition of titanium-carbide base containing 30 wt. per cent. of nickel and 8 wt. per cent. of a solid solution of niobium, tantalum and titanium carbides). In both of the engines used for the tests the blades were subjected to an operating temperature of 1500°F. (815°C.). In one, however, the stress to which the blades were exposed (21,000 p.s.i.; 9·5 t.s.i.; 15 kg./mm.^{2}) was about one-third higher than in the other. Blade design and the evaluation procedure used are outlined and details are given of the results obtained.

On the basis of strength alone cermets are considered to offer promise of satisfactory service in turbines operating at increased temperatures. Lack of ductility and poor impact-resistance are major problems yet to be overcome.

III. *Refractory Metals*

Developments in Chromium-base Alloys

R. W. FOUNTAIN and M. KORCHYNSKY: 'Chromium-base Alloys for High-Temperature Applications', pp. 207–28.

The aim of the paper (which is based on a *bibliography* of 52 items) is to review the salient developments in the study of chromium and chromium-base alloys and to indicate the approaches to the problem of evolving chromium-base high-temperature alloys which promise most success.

The problems involved, and the work carried out in an attempt to overcome them, are outlined in the introductory sections of the paper. On the basis of the work described, the major obstacle appears to be the lack of ductility exhibited by chromium-base alloys: it has not been found possible to hot work those with the highest creep-resistance, and all the alloys are brittle at room temperature. On the assumption therefore that an increase in the ductility of chromium *per se* would result in a corresponding increase in the ductility of its alloys, considerable research has been conducted on the preparation of high-purity chromium and determination of its properties. This work and its main results are considered, and in a subsequent section reference is made to investigations of the effects, on the room-temperature ductility of chromium, of the following impurities or alloying additions: oxygen, carbon, nitrogen, cerium, aluminium, copper nickel, cobalt, manganese, iron, silicon, tungsten.

On the basis of the relatively few studies reported, the authors' main conclusion is that 'the successful solution of the chromium-purification problem has not fully substantiated the original expectations that higher purity would result in adequate ductility of chromium metal and, consequently, of chromium-base alloys. The tensile ductility of chromium has been improved remarkably, and the temperature of transition from ductile to brittle fracture substantially lowered. The overall ductility of the purest chromium available still remains below the level generally required for engineering purposes. In the field of chromium-rich alloys the effect of enhanced purity on room-temperature ductility and hot workability is even less marked'. Additional research might, it is considered, however, provide more encouraging results.

Influence of Alloying Additions on the Transition Temperature of Chromium

E. P. ABRAHAMSON and N. J. GRANT: 'Transition Temperatures of Chromium and Chromium-base Alloys', pp. 229–42.

Details are given of work carried out to investigate the feasibility of using a simple deoxidation and denitrogenation addition to produce ductile chromium. The suitability of the following additions was studied: boron, beryllium, carbon, calcium, cerium, niobium, aluminium, silicon, titanium and zirconium. Transition temperatures were determined by means of a bend test.

Molybdenum, Its Alloys and Its Protection

J. J. HARWOOD and M. SEMCHYSHEN: 'Molybdenum, Its Alloys and Its Protection', pp. 243–72.

The authors review the current state of development of molybdenum and its alloys in relation to the use of the materials in high-temperature applications.

The sections comprising the review are concerned with discussion of: data relating to the physical and mechanical properties of molybdenum; the solubility in molybdenum of alloying elements (nickel, silicon, cobalt, aluminium, iron) and their effect on rupture-strength, hardness and workability; recrystallisation behaviour; tensile properties; transition-temperature characteristics; creep-rupture properties; molybdenum-rhenium alloys; protection of molybdenum from oxidation at high temperatures (mainly by application of various types of nickel-containing coating); and weldability.

Properties of Molybdenum-Alloy Turbine Blades

R. G. FRANK: 'Properties of Molybdenum-Alloy Turbine Buckets', pp. 273–91.

Summary of data derived from tests on specimens cut from turbine blades fabricated from a molybdenum alloy containing 0·5 per cent. titanium. Forging procedures are also described.

The data presented cover tensile, stress-rupture, impact, hardness and recrystallisation characteristics.

Processing and Properties of Molybdenum-base Alloys

T. K. REDDEN: 'Processing and Properties of Selected Experimental Molybdenum-base Alloys', pp. 292–305.

Review of work which the General Electric Company has carried out on processing of zirconium-, titanium-, vanadium- and tantalum-containing alloys. Data on the tensile and rupture properties of each of the alloys studied are included in the paper.

Properties of Tungsten, Tantalum, Niobium and Rhenium

J. W. PUGH: 'Refractory Metals: Tungsten, Tantalum, Columbium and Rhenium', pp. 306–18.

Data available on the properties of the refractory metals tungsten, tantalum, niobium, and rhenium are reviewed in a general assessment of the suitability of the four materials for use in high-temperature applications.

IV. *Strengthening by Dispersion of Insoluble Particles*

Factors Involved in Dispersion Hardening

F. V. LENEL: 'Observation of SAP and Present Theories for Its Remarkable High-Temperature Strength', pp. 321–31.

The author discusses, mainly in terms of data reported for 'SAP', the factors involved in optimum dispersion-hardening. Reference is, however, made also to work on dispersion-hardened nickel, copper and molybdenum.

Dispersion Hardening of Titanium

R. W. JECH, A. D. SCHWOPE and E. P. WEBER: 'The Development of SAP-type Structures in Titanium for Elevated-Temperature Service by Powder-Metallurgical Techniques', pp. 332–41.

Report of work by Clevite Research Center on the development of dispersion-hardened titanium alloys.

V. *Vacuum Melting and Its Effects on Properties*

Effects of Vacuum Melting on Cast Nickel-base Alloys

C. M. HAMMOND and R. A. FLINN: 'Effects of Vacuum Melting on Gas Content and Metal Structure of Cast Nickel-base Alloys', pp. 345–63.

In an attempt to throw light on the factors underlying the variations in properties which have been reported in materials produced by vacuum-melting techniques, the authors examine the reactions involved in vacuum melting and then illustrate, by reference to experimental data, the effects of these reactions on the structure and high-temperature properties of vacuum-melted nickel-base alloys. The effects of vacuum melting are manifested in two fields: (1) control of gas content (melt/atmosphere reactions, deoxidation practice, gas evaluation on solidification); (2) control of non-gaseous minor elements (removal by distillation, reduction of trace elements from crucible materials). The thermochemistry involved in these two fields is reviewed, and this theoretical outline is then used as a basis for discussion of experimental data available on specimens of 'Guy Alloy', 'Inco 700' and 'GMR-235' melted in air, *in vacuo* or under an argon atmosphere.

That part of the work dealing with the stress-rupture properties of the three alloys has been previously described in *Jnl. Metals*, 1956, vol. 8, Oct., Sect. 1, pp. 1450–6, and the relevant abstract in *Nickel Bulletin*, 1957, vol. 30, No. 1–2, pp. 18–19 gives particulars of compositions and reproduces tables comparing the properties of specimens produced by the three melting techniques. In the present paper the emphasis is on the relative efficacy of vacuum melting in controlling gas content (principally nitrogen), and on the elimination of trace elements. The nitrogen content of 'Guy Alloy' is correlated with elongation data at high temperatures, and photomicrographs are presented illustrating the cracking behaviour of the alloys at high nitrogen contents.

Evaluation of Nickel-base Alloys Melted and Investment-Cast in Vacuo

P. W. BEAMER and J. J. EISENHAUER: 'Evaluation of Vacuum-Melted Vacuum-Investment-Cast Nickel-base Alloys', pp. 364–77.

The investigation described was carried out in the light of the success attained in the relatively widespread application of vacuum-melting techniques

to the production of wrought nickel-base heat-resisting alloys, and was intended to determine the feasibility of extending the scope of such techniques to the production of investment-cast turbine components. Three nickel-base alloys, 'Waspaloy', 'Udimet 500' and 'Inco 713', were selected for study, on the assumption that, with minor modifications in composition, they might be rendered suitable for investment casting, and that their stress-rupture properties might equal or exceed those of the wrought materials.

Test bars were vacuum-investment-cast from master heats, the compositions of which were within the normal compositional specifications and therefore representative of commercially available grades. The heats of 'Waspaloy' and 'Udimet 500' were vacuum-melted, but an air-melted heat was the only large master heat available for 'Inco 713'. Specimens of the latter alloy were tested in the as-cast condition and those of the other alloys were solution-treated and aged before testing. Stress-rupture tests were carried out at 1500°, 1600° and 1700°F. (815°, 870° and 925°C.) and tensile tests at room temperature, 1100°, 1200° and 1500°F. (595°, 650° and 815°C.). To compare the advantages of vacuum- and inert-atmosphere melting and casting, tests were also made on 'Waspaloy' specimens melted and cast, from the same master heat, under an argon atmosphere. Particulars are given of melting and casting procedures and of the degree to which the composition of the master heat was eprroduced after remelting.

From the data presented the authors conclude that the stress-rupture properties obtained by vacuum investment casting are equal to, or better than, those obtained for similar alloys using conventional techniques; that ductility is improved as a result of vacuum investment casting; and that the use of large heats of alloy previously melted *in vacuo* does not significantly lower or affect the level of properties.

Consumable-Electrode Vacuum Melting of Nickel-base High-Temperature Alloys

R. K. PITLER, E. E. REYNOLDS and W. W. DYRKACZ: 'Consumable-Electrode Vacuum Remelting of High-Temperature Alloys', pp. 378–87.

The paper reports the successful application of consumable-electrode vacuum melting to the production of 'Waspaloy', 'M-252', 'A-286', and 'Multimet N-155'. The advantages of this melting technique are discussed in relation to: the lower gas content of the alloys and their freedom from inclusions; the improvements in forgeability resulting from higher cleanliness and elimination of segregation; the ability of vacuum melting, due to the associated rapid cooling rate which minimises segregation and refines the ingot structure, to produce larger-size ingots than has been hitherto possible with highly-alloyed materials; improvements in mechanical properties (mainly room-temperature and elevated-temperature ductility and fatigue-strength) which render possible modifications in alloying and heat-treatment which, in their turn, result in even higher strengths without deleterious effects on ductility; better uniformity of structure and improved response to working and heat-treatment, resulting in less scatter in property values.

Influence of Crucible Materials on Vacuum-Melted Nickel-base Alloys

R. F. DECKER, J. P. ROWE and J. W. FREEMAN: 'Relations of High-Temperature Properties of a Nickel-base Precipitation-Hardening Alloy to Contamination by Crucibles', pp. 388–406.

During experiments made to study the effects of melting-practice variables on the high-temperature properties of a nickel-chromium-cobalt-base alloy a relationship (associated with zirconium and boron pick-up and the subject of the present paper) was established between the type of refractory used in induction-melting and the high-temperature properties of the material.

The information contained in the paper has been previously reported in *Nat. Advisory Committee for Aeronautics, Technical Note* 4049: see abstract in *Nickel Bulletin*, 1957, vol. 30, No. 10, p. 183.

See also abstract on p. 370.

Effects of Vacuum Melting on the High-Temperature Properties of Nickel-base Alloys

F. M. RICHMOND: 'The Effect of Vacuum Melting on the High-Temperature Properties of Nickel-base Superalloys', pp. 407–26.

In this review the author draws attention to data illustrating the improvements in properties obtained in nickel-base high-temperature alloys by use of vacuum melting and by complementary modifications in the composition of alloys produced by the technique. It is emphasised that the primary rôle of the vacuum-melting process is to lower the gas content of the alloys and to eliminate the need for a slag blanket, and that the improvements in high-temperature properties of nickel-base alloys are not attributable solely to the process *per se*. The elimination of manganese and silicon has contributed to increased ductility, and small additions of boron and zirconium (see previous abstract) have had a considerable beneficial effect on rupture life. These compositional modifications have been utilised simultaneously with vacuum-melting techniques, and it is difficult to separate the effects of the two factors, but data exemplifying the effects of boron and zirconium on vacuum-melted alloys are presented.

Since the installation of a 1000-lb.-capacity vacuum-induction furnace at Universal Cyclops Steel Corporation, stress-rupture and tensile tests have been made on various vacuum-melted nickel-base high-temperature alloys. The major part of the present paper is devoted to the presentation and discussion of the results of such tests on the cobalt-nickel-chromium alloy 'J-1570' and the nickel-chromium-(cobalt)-base alloys 'GMR-235', 'Udimet 500',

'M-252' and 'Waspaloy'. All the heats studied contained boron (and, in the case of 'J-1570', 'Udimet 500' and 'M-252', zirconium) additions. Particulars of heat-treatment are given. Tensile and rupture strengths are plotted parametrically and, where available, comparative data on air-melted heats of the same grades of alloy are incorporated in the plots. Diagrams illustrate (1) the effects, on the tensile and rupture properties of 'Waspaloy' and 'M-252', of vacuum melting and compositional modifications, and (2) the effects, on a commercial alloy at constant test temperature and stress, of melting practice, composition, solution-treatment and fabrication practice.

VI. *Effect of Testing Environment on Properties*

Influence of Environment on the Creep Properties of Nickel and Nickel-base Alloys

D. A. DOUGLAS: 'The Effect of Environment on High-Temperature Creep Properties of Metals and Alloys', pp. 429–47.

A review of all the research carried out to determine the effect of environment on the creep properties of metals and alloys is difficult to present in compact form, particularly in view of the fact that industrial work in this connection has related to specific problems. In this paper, therefore, the author refers only to data reported in the literature which illustrate the effects of the following types of environment: oxidising, neutral or inert, reducing, corrosive, and nitriding.

The data discussed relate mainly to tests on nickel and 'Inconel'. The major points arising from consideration of the effects of the different environments are that metals which do not form protective oxide films are stronger in neutral or reducing environments than in air; low-melting volatile oxides can attack oxidation-resisting alloys; some high-temperature alloys exhibit an increase in creep-strength in air, compared with that exhibited in inert or reducing atmospheres; hydrogen may have deleterious effects on some materials at high temperatures; liquid metals affect strength properties in proportion to the rate and depth of the corrosive attack; and 'Inconel' nitrides at 1500°F. (815°C.) in molecular nitrogen, resulting in a distribution of nitride particles which significantly improves creep-strength.

In the author's discussion of these findings particular attention is paid to the theoretical significance of those indicating the beneficial effect, on creep properties, of the presence of oxide and other surface films. A survey of the literature is considered to justify the following generalisations: (1) When transgranular slip is making the least contribution to the overall deformation process, nickel and 'Inconel' appear to be the most sensitive to the effects of surface conditions. (2) The strengthening effect of the oxide film is most pronounced when there is a large surface-area/volume ratio, or when the grain-size is large in relation to the cross-section of the specimen. (3) It is unlikely that these results can be attributed to changes in grain-boundary composition, since ceramic coatings have similar effects to those of oxide films. (4) Cracking behaviour is a related and not a controlling factor. (5) It is most unlikely that the strength of the surface film is sufficient to support the direct tensile load necessary to produce the changes observed.

Creep-Rupture Properties of Nickel in Air and in Vacuo

P. SHAHINIAN and M. R. ACHTER: 'A Comparison of the Creep-Rupture Properties of Nickel in Air and in Vacuum', pp. 448–65.

The information presented is similar to that reported by the authors in *U.S. Naval Research Laboratory Report* 5036: see abstract in *Nickel Bulletin*, 1958, vol. 31, No. 6, pp. 157–8.

Influence of Sodium Hydroxide, Air and Argon on the Stress-Rupture Properties of Nickel

H. T. MCHENRY and H. B. PROBST: 'Effect of Environments of Sodium Hydroxide, Air, and Argon on the Stress-Rupture Properties of Nickel at 1500°F.', pp. 466–85.

See abstract (in *Nickel Bulletin*, 1959, vol. 31, No. 6, pp. 173–4) of *Nat. Advisory Committee for Aeronautics, Technical Note* 3987, in which the investigation described was previously reported.

Creep-Rupture Properties of Molybdenum Alloys in Helium and in Vacuo

D. D. LAWTHERS and M. J. MANJOINE: 'The Effect of Testing Atmospheres on the Creep-Rupture Properties of Molybdenum-base Alloys at 1800°F.', pp. 486–97.

The paper presents data on the creep-rupture properties of molybdenum alloys (containing niobium, titanium or zirconium) tested *in vacuo* or in an atmosphere of helium.

VII. *Oxidation Resistance*

Influence of Alloying Additions on the Oxidation-Resistance of Chromium

E. P. ABRAHAMSON and N. J. GRANT: 'Oxidation-Resistance of Binary Chromium-base Alloys', pp. 501–9.

The investigation reported was carried out to determine the influence, on the oxidation-resistance of hydrogen-purified electrolytic chromium, of alloying additions of up to 40 at. per cent. of the following elements: niobium, cobalt, iron, iridium, manganese, molybdenum, nickel, palladium, platinum, rhenium, rhodium, ruthenium, tantalum, titanium, vanadium, zirconium. The respective binary alloys were melted in an argon atmosphere, and test specimens were exposed to flowing air for 96 hours at

1800°F. (980°C.). In the paper, oxidation-resistance is plotted, as a function of alloy content, in terms of weight-gain, using the nickel-chromium alloy 'Nichrome' as a standard of comparison. Identification of the oxides present in the oxide films was carried out by X-ray techniques.

With the exception of iridium, all the transition elements investigated caused an initial increase in the oxidation-resistance of chromium. This increase, which occurred with fractions of an atom per cent. of solute additions, was reflected in an oxidation-resistance three to fifteen times higher than that of pure chromium. (The oxidation rate of the most resistant alloy studied, a 70-30 chromium-palladium alloy, was, however, still three times that of 'Nichrome'.) Oxidation-resistance increased as intermetallic compositions were approached or reached. In the four binary systems (Cr-Ta, Cr-Ti, Cr-Mo, Cr-Ni) selected for study of the influence of oxidation on nitrogen solution, a rapid initial increase was noted in the nitrogen content of the specimens with initial solute additions.

Oxidation of Tungsten and Molybdenum

J. W. SEMMEL: 'The Oxidation of Tungsten and Molybdenum from 1800° to 2500°F.', pp. 510-19.

The relative oxidation-resistance of the two metals was determined by tests in which specimens were exposed to flowing air at temperatures in the range 1800°-2500°F. (980°-1370°C.).

Film Formation and Oxide Growth on Nickel-containing Gas-Turbine Alloys

J. F. RADAVICH: 'High-Temperature Oxidation of Gas-Turbine Alloys', pp. 520-37.

Previous work on high-temperature alloys had shown that there are essentially two types of oxide growth: one occurs (e.g., on stainless steels) by the formation of a thin film, on top of which oxide nodules nucleate and grow; the other (found, for example, on the alloys 'N-155' and 'Hastelloy C') occurs in the form of a thin uniform oxide film. The study now reported was carried out to determine the effects of molybdenum, cobalt and tungsten on film formation and oxide-scale growth on an iron-base alloy containing 20 per cent. each of chromium and nickel. The influence of the individual elements was evaluated singly in alloys containing 5 per cent. of the respective addition, but, in one case, a combined addition of 5 per cent. cobalt and 5 per cent. molybdenum was made to the basis composition. All the alloys were oxidised for 5 and 15 minutes at 800°C. and for 10 hours at 1000°C., and comparative tests were made on the nickel-base turbine alloys 'Inconel', 'Inco 702' and 'Udimet 500'. The oxide film formed at 800°C., and the scale formed at 1000°C., were studied by means of optical microscopy, electron microscopy, reflection electron diffraction, electron diffraction in transmission, X-ray diffraction and X-ray fluorescence analysis. Photomicrographs illustrating the oxidation effects observed are included in the paper.

The author's summary of the findings of the investigation is quoted below:

'1. Additions of molybdenum suppress the formation of oxide nodules, and a spinel-type structure rather than a rhombohedral phase dominates the oxide-film structure. The molybdenum addition causes the oxide film to blister as it is cooled. Since lower-temperature studies of these same alloys do not show the blistering effect, it is felt that the volatile molybdenum oxide is formed at this high temperature and causes the blistering.

'2. Additions of cobalt do not change the mode of the oxide film growth; adherence of the oxide scale is increased.

'3. The combined effect of molybdenum and cobalt appears to be the same as that of molybdenum only. The oxide film blisters, the oxide nodules are suppressed, and a spinel-type structure is formed.

'4. The main effect of the addition of tungsten is to cause severe blistering of the oxide film and spalling of the oxide scale. The character of the growth of the oxide film is somewhat changed, but nodules are still present.

'The films on the 'Inconel', 'Inco 702' and 'Udimet 500' alloys are composed of small crystals, are very adherent, and grow in an oriented way. The orientation persists through the oxidation times used in this study, and the crystal size increases. The oxide film on the 'Inconel' grows thicker than that on either the 'Inco 702' or 'Udimet 500'.

'At 1000°C. additions of cobalt and molybdenum improve oxide adherence.

'The results of the studies of the interface of the oxide film and oxide scale showed that the oxide film is made up of at least three layers. The most interesting and unusual layer has a glassy nature, probably amorphous silica or silicate, which plays an important rôle in the adherence of the scales and may have a direct effect on the attack rate.

'The high-temperature oxidation-resistance of the high-nickel alloys appears to be related to (1) the oriented oxide growth of the initial film, (2) excellent adherence of the oxide scale, and (3) the presence of the Cr_2O_3 in the scale. In the more complex alloys, 'Inco 702' and 'Udimet 500', interfacial layers of NiO and αAl_2O_3, respectively, are detected in addition to Cr_2O_3 and spinel phases, and may play an important rôle in resistance to oxidation.'

Spectral Emittance of 'Inconel' and Austenitic Stainless Steel

J. C. RICHMOND and J. E. STEWART: 'Spectral Emittance of Uncoated and Ceramic-Coated 'Inconel' and Type 321 Stainless Steel.'

Nat. Aeronautics and Space Administration, Memorandum 4-9-59*W*, April 1959; 30 pp.

The investigation reported was carried out to obtain spectral emittance curves for two materials of interest as materials of construction for aircraft

and missiles operating at hypersonic speeds: the nickel-chromium-base high-temperature alloy 'Inconel', and a titanium-stabilised 18-8-type chromium-nickel stainless steel (A.I.S.I. Type 321).

The normal spectral emittance of the two materials was measured, at 900°, 1200°, 1500° and 1800°F. (480°, 650°, 815° and 980°C.), over the wavelength range 1·5–15 microns. The influence of the following surface treatments was evaluated: electropolishing; sandblasting; electropolishing or sandblasting followed by oxidation in air for ½ hour at 1800°F. (980°C.); application of two types of ceramic coating.

The normal spectral emittance of both alloys in the electropolished condition was low, and decreased only slightly with increase in the wavelength; that of the sand-blasted specimens was somewhat higher and did not vary appreciably with wavelength. In the case of the electropolished-and-sand-blasted stainless-steel and the electropolished 'Inconel' specimens, oxidation treatment greatly increased normal spectral emittance (introducing some spectral selectivity into the curves), but the same treatment resulted in only a moderate increase in that of the sand-blasted 'Inconel' specimens. The coated specimens of 'Inconel' exhibited a higher spectral emittance at all wavelengths than the corresponding stainless-steel specimens.

The normal spectral emittance of all the specimens measured tended, at all wavelengths, to increase with rise in temperature.

Fatigue-Strength of Heat-Resisting Alloys at Elevated Temperatures

M. HEMPEL: 'Fatigue Tests on Heat-Resisting Alloys in the Temperature Range 800°–1000°C.'

Stahl u. Eisen, 1959, vol. 79, Oct. 15, pp. 1501–5.

In this commentary-review of recent literature on the fatigue-strength of heat-resisting alloys in the temperature range 800°–1000°C., the author attempts a consolidation of the reported data in terms of notch effects, the interpretation and presentation of such data, and the relationship between fatigue-strength and time and temperature of testing and the type and condition of the alloy tested.

The review is based on a *bibliography* of twenty-seven items. The data discussed relate, *inter alia*, to 'S-590', 'S-816', 'G-18B', 'Multimet N-155', 'Vitallium', 'Refractaloy 26', 'G-32', 'Haynes Stellite 31', and alloys of the 'Nimonic' series.

Influence of Boron and Zirconium Additions on the Properties of a Nickel-base Heat-Resisting Alloy

R. F. DECKER, J. P. ROWE and J. W. FREEMAN: 'Boron and Zirconium from Crucible Refractories in a Complex Heat-Resistant Alloy.'

Nat. Advisory Committee for Aeronautics, Report 1392, 1958; 38 pp.

The report summarises work arising from the discovery of the improvements in creep-rupture properties which resulted from the introduction (via the crucible refractory during induction vacuum melting) of trace amounts of boron and zirconium into an alloy of the following composition: nickel 55, chromium 20, cobalt 15, molybdenum 4, titanium 3, aluminium 3, per cent. It supersedes and consolidates *N.A.C.A. Technical Notes* 4049 and 4286, abstracts of which appeared in *Nickel Bulletin*, 1957, vol. 30, No. 10, p. 183; 1959, vol. 32, No. 1, pp. 16–17.

Influence of Directional Grain Structures on the Creep-Rupture Properties of a Cast Nickel-base Alloy

F. L. VERSNYDER and R. W. GUARD: 'Directional Grain Structures for High-Temperature Strength.'

Amer. Soc. Metals, 1959, *Preprint* 168; 9 pp.

The deformation and fracture characteristics of metals and alloys at elevated temperatures are known to be influenced by the nature and behaviour of their grain boundaries, and it is usually observed that fracture propagates along the grain boundary. The present paper records the results of research aimed at determining the feasibility of minimising susceptibility to intergranular fracture by producing in the material a directional structure with grain boundaries oriented parallel to the stress axis.

The material chosen for study was a nickel-chromium-aluminium alloy (nominal composition: nickel 75·5, chromium 21, aluminium 3·5, per cent.) which previous work had shown to exhibit low tensile and rupture ductility and a high susceptibility to intercrystalline cracking. The procedures used to obtain a columnar grain structure in the cast ingot are described. To provide a basis for comparison, an ingot with an equiaxed structure was also produced, and the creep-rupture properties of the two castings were determined, as a function of grain-boundary direction, on specimens cut from the ingots in a longitudinal, transverse and oblique direction.

The test results indicate the considerable increase in high-temperature ductility and creep-rupture strength associated in the alloy with columnar grains extending parallel to the applied stress. Ductility was four to ten times higher than that obtained with an equiaxed structure, and rupture strength was increased by 15–20 per cent. The directional structure inhibits the normal intergranular-fracture mode, and hence the fracture becomes predominantly transgranular, a basic principle which it is considered could be applied to any material whose strength is limited by a tendency to intergranular fracture.

The experiments on specimens exhibiting various orientations of the columnar grain axis with respect to the stress axis indicated that the improvement in properties is related to the directionality of the grain boundary itself and not to the preferred orientation of the grains or to the preference for certain boundary orientations. This finding was confirmed by the observation that the factors primarily affected were fracture behaviour and ductility, and that creep behaviour was unaffected at small strains.

Creep Properties of Molybdenum-containing Austenitic Steels

H. W. KIRKBY: 'Creep Properties of Two Molybdenum-bearing Austenitic Steels.'

Alloy Metals Review, 1959, vol. 9, June, pp. 2–7.

In view of cracking troubles encountered in the use of welded chromium-nickel-niobium austenitic steel of 18-12-1 type in steam-power plant, increasing interest is being shown in the high-temperature properties of the molybdenum-containing austenitic steels. The creep properties of steels of 18-12-1 type are fairly well established, but little data are available on the creep behaviour of the niobium-stabilised and unstabilised molybdenum-containing grades (references to relevant literature are given in the paper). The work now reported was carried out to obtain creep data on two such molybdenum-bearing steels, one similar to Type 316 of the A.I.S.I. series, the other based on the 18/12/1 grade (see composition below).

Steel	C %	Cr %	Ni %	Mo %	Nb %
'F.V. 555' ..	0·1 max.	16	10½	2¼	—
'F.V. 548' ..	0·1 max.	16	12	1½	10×C

Test pieces were cut, tangentially to the wall thickness, from steampipe produced by hot-piercing methods, and creep-ductility was compared with that of similar specimens of 18-12-1Nb steel. In the case of the 'F.V. 555' steel some results are reported also for specimens obtained from a forged tube billet. Creep-rupture data derived from weld deposits, produced using a molybdenum-bearing 18-8-type electrode ('Armex GT'), are compared with data derived from tests on austenitic weld deposits of niobium-bearing molybdenum-free type. Heat-treatments (particulars of which are given) were selected with a view to obtaining the optimum combination of creep-strength and creep-ductility. Creep-rupture tests were carried out at 650° and 700°C.

The data presented indicate that the creep-resistance (particularly creep-ductility) of the molybdenum-bearing austenitic steels is superior to that of 18-12-Nb steel, the highest creep-ductility being exhibited by the 'F.V. 555' steel. Of the two molybdenum-bearing steels, the niobium-stabilised 'FV. 548' grade exhibited the higher creep-strength, but creep-ductility was somewhat inferior to that of the unstabilised steel. Rupture curves derived from tests at 700°C. indicate that the rupture-strengths of the two steels at 100,000 hours may not differ as much as might be expected on the basis of rupture-strengths at 10,000 hours.

The author considers that the rupture data obtained for 'F.V. 555' provide some justification for the American decision to raise the working stresses specified for Type 316 steel, though further testing is required for confirmation of this assumption. Data (not presented in the present paper) give some reason for believing that the creep-ductility of the molybdenum-bearing steels is very much less sensitive to the effects of high-temperature solution-treatment than that of the standard 18-12-1Nb steel.

The results of tests on weld deposits give further evidence of the superior creep-ductility of the molybdenum-bearing, *vis-à-vis* that of the molybdenum-free, steels.

High-Temperature Compressive Strength of Stainless-Steel Sandwich Structures

E. E. MATHAUSER and R. A. PRIDE: 'Compressive Strength of Stainless-Steel Sandwiches at Elevated Temperatures.'

Nat. Aeronautics and Space Administration, Memorandum 6-2-59*L*, June 1959; 50 pp.

The advantages of high-strength, stiffness and light weight offered by sandwich construction, properties which are prerequisites for aeronautical structures fabricated from heat-resisting stainless steels, have focused attention on two types of current interest: the honeycomb core and the corrugated core. Little data are available, however, on the strength of either type at temperatures higher than those at which adhesive bonding becomes unsuitable, and the present study was initiated with the aim of obtaining the required information, for the range 80°–1200°F. (25°–650°C.), by tests on resistance-welded single- and double-corrugated cores and brazed hexagonal- and square-cell honeycomb cores. Single-cored sandwich specimens of the former type were fabricated from '17-7 P.H.' precipitation-hardenable chromium-nickel steel, and 18-8-type stainless steel was used for the double-cored specimens; all of the honeycomb-core specimens were produced from '17-7 P.H.' steel.

The specimens were tested in axial compression, without side support, to determine the maximum or crippling strengths and modes of failure. The experimental data obtained are compared in the report with data predicted by methods described. Crippling strengths were predicted from the calculated maximum strength of the individual plate elements of the sandwiches, and from a correlation procedure which permitted calculation of the elevated-temperature crippling strength from experimental data on room-temperature crippling strengths.

The crippling strengths and modes of failure predicted for the corrugated sandwiches were found, in general, to be in good agreement with the experimental data, but the strengths predicted for the honeycomb-core specimens showed only fair agreement with the experimental results. Photographs showing the modes of failure of some of the tested specimens are included in the report.

Evaluation of Austenitic-Steel Superheater Tubing After Long-Time Exposure to Steam at High Temperatures

C. L. CLARK, J. J. B. RUTHERFORD, A. B. WILDER and M. A. CORDOVI: 'Metallurgical Evaluation of Superheater-Tube Alloys after Six-Months' Exposure at Temperatures of 1100° to 1500°F.'

Amer. Soc. Mechanical Engineers, 1959, *Preprint* 59-*Pwr*-1; 33 pp.

The research programme to which the paper relates was initiated, by the Research Committee on High-Temperature Steam Generation of the American Society of Mechanical Engineers, to evaluate the performance characteristics of selected austenitic and ferritic steels and alloys when exposed, in the form of tubing, to pressurised steam at high temperatures for periods of up to 36 months. Resistance to creep, corrosion and thermal shock, metallurgical stability, and the effects of oxide films on thermal conductivity were among the factors investigated.

The materials selected for evaluation are listed below:

Ferritic Steels	*Austenitic Materials*
Cr-Mo-V	Type 304 (18-8) steel
2¼ Cr-1 Mo	Type 347 (Nb-stabilised 18-8) steel
5 Cr-Mo-Ti	Type 321 (Ti-stabilised 18-8) steel
2¼ Cr-1 Mo (welded)	Type 316 (16-13-Mo) steel
5 Cr-Mo	Type 310 (25-20) steel
9 Cr-Mo	16 Cr-25 Ni-6 Mo
5 Cr-Mo (welded)	17 Cr-14 Ni-Cu-Mo
3 Cr-1 Mo	15 Cr-15 Ni+nitrogen
5 Cr-Mo-Si	'Inconel'
5 Cr-Mo-Ti (welded)	'Incoloy'

The tests are being carried out in five test rigs: the two containing the ferritic steels are operated at 1100° and 1200°F. (595° and 650°C.); the remaining three, containing the austenitic tubes, operate at 1200°, 1350° and 1500°F. (650°, 735° and 815°C.). The steam pressure is, in each case, 2000 p.s.i. The outer surface of the test tubes, which are 2 in. (5 cm.) in outer diameter, 42 in. (105 cm.) long, and have a wall thickness of ½ in. (1·25 cm.), is exposed to air, and there is no temperature gradient across the tube wall.

After the first six months operation, a third of the tubes were removed from each unit and their dimensions and metallurgical characteristics (room- and high-temperature tensile and impact properties, hardness, flattening characteristics, and macro- and microstructural features) were compared with those determined for similar tubing which had not undergone testing. The data obtained for each of the materials studied are tabulated in detail in the paper, and discussion of the metallographic findings is supplemented by photomicrographs. The authors' conclusions are quoted below:

'1. Visual examination indicated differences in the appearance of the scale on the outside surface of the ferritic tubes after exposure at 1100° and 1200°F. (595° and 650°C.), but microexamination indicated relatively slight differences in the amount of actual attack, especially at 1100°F. At 1200°F. the measured depth of scale for these steels varied from 0·010 to 0·017 in. (0·025 to 0·425 mm.), with 9 Cr-1Mo showing the least, and 2¼ Cr-1 Mo the greatest, amount of scaling. At both temperatures the scale thickness on the ID was comparable to that on the OD. This is in agreement with the known effect of increasing chromium content in improving the resistance to scaling in both air and steam, especially at temperatures in excess of 1100°F. (595°C.).

'2. With the austenitic steels the scale on the OD was slight at each of the three temperatures. While visual appearance of the ID indicated little attack, certain of the tubes, especially 15-15N at 1350° and 1500°F. (735° and 815°C.), contained several inches of flaky scale, thus indicating appreciable attack by the steam.

'3. The mechanical properties of the ferritic steels were not appreciably changed during exposure at 1100° and 1200°F. (595° and 650°C.). The same was also true of the austenitic steels with respect to their tensile and yield-strength values. However, with certain of the austenitic steels, a marked decrease occurred in the room-temperature ductility and impact properties as a result of exposure at the elevated temperatures. The steels undergoing the greatest changes were 16-25-6, Type 310, 15-15N, and 17-14-Cu-Mo.

'4. A definite correlation was not found to exist between the high-temperature rupture properties and the degree of bulging or, in the case of the tubes that have ruptured, in the rupture time.

'5. To date, failures have occurred in the 1500°F. tests of Type 347 and 310 and the remaining tubes of these analyses were removed because of excessive bulging. 'Incoloy' and 'Inconel' alloys were also removed because of excessive bulging. One tube of Type 321 and 17-14-Cu-Mo have likewise failed, but the two remaining tubes of each of these analyses are still under test.

'6. All of the austenitic tubes that failed in the 1500°F. test unit showed a marked nitrogen pick-up on the surface, and this probably accounted for some, at least, of the shallow OD cracking visible on the macro sections. The question exists whether this same condition would occur in combustion gases.

'These conclusions apply only to the given test conditions. With higher rates of steam flow through the tubes, or with combustion gases on the outside of the tubes, different results may have been obtained.'

Use of 'Inconel 713C' for Hot Dies in Press Forging

'Hot Dies Aid Forging.'

Steel, 1959, vol. 145, Oct. 5, pp. 92-3.

A hot blank forged by a cold die loses heat so rapidly that, within seconds, the production of thin sections and adequate penetration of the metal into deep die cavities are rendered impossible.

The difficulty encountered in removing the cooled part from the die necessitates use of a greatly exaggerated draft or edge angle, and the cost of machining involved in finishing the component often exceeds that of forging. In this short article details are given of a hot-die technique, developed by the Armour Research Foundation, Illinois Institute of Technology, Chicago, which, it is claimed, produces a rough forging approaching the dimensions of the finished part, and hence, drastically reduces the amount of machining needed and minimises the number of dies required in the sequence.

The research workers, faced with the problem of producing a die which would not deform when heated at 1600°F. (870°C.) to press a stainless-steel blank at 2200°F. (1205°C.), selected for investigation 'Inconel 713C'* (and another alloy which subsequently failed) as possessing the required compressive yield strength and oxidation-resistance. The alloy was cast by a technique involving use of a mouldable graphite mixture, and the dies so produced are stated to have forged thin and intricate components, at temperatures up to 1600°F. (870°C.) and pressures up to 80,000 p.s.i. (35·5 t.s.i. ; 56 kg./mm.^{2}), with a precision considerably higher than that produced by standard methods.

The dies are assembled from four cast layers, the second of which contains the 'Calrod' heating units which maintain the temperature at 1600°F. (870°C.). The lubricant developed for use with the dies, comprising a mixture of graphite and potassium iodide, is applied to the die in powder form. When heated, the salt melts and then becomes a carrier for the graphite.

Surface Treatments for Hot-Work Dies

'Plate Life Into Your Dies: New Process Cuts Down Premature Failures.'

Iron Age, 1959, vol. 184, Aug. 27, pp. 86–8.

Dies used in the hot-working of heat-resisting alloys (e.g., in heavy forging, hot heading, press forming, stretch forming, hot drawing and extrusion) are subjected to temperatures ranging from 500° to 1200°F. (260° to 650°C.). Cheapness, satisfactory heat conductivity, machinability, oxidation-resistance, abrasion-resistance and adequate ductility are prerequisites for materials used in such applications, and efforts have been made to obtain the desired combination of properties either in the development of alloy die steels or by coating the surface of the basis metal with suitably resistant materials. Two such surface treatments, both developed by Todco, California, are described in the article.

One, designated 'Pyro-Plate' and claimed to have increased the life of dies by at least 25 per cent., and, in certain cases, by as much as 85 per cent., involves coating the die surface with a nickel-containing composition which when heated forms an alloy at the basis-metal/coating interface. The nickel coating so obtained is adherent, sufficiently ductile to permit some flexibility of the die surface, highly resistant to oxidation and corrosion, and may be precipitation-hardened to Rc 65–68. The nickel is claimed moreover to provide maximum resistance to intergranular oxidation by infiltrating the die substrate along the grain boundaries.

The second coating process, 'Pyro-Tung', confers on the basis metal an abrasion-resistance stated to be far superior to that of a hardened steel. The 'Pyro-Tung' coating, containing up to 80 wt. per cent. of crystalline tungsten carbide, may be precipitation-hardened to Rc 68–70, and the wear-resistance so obtained is supplemented by oxidation-resistance provided by the nickel comprising the remainder of the coating.

Being of paint-like consistency, both coatings may be applied to ferrous materials by brushing, dipping or spraying. The 'Pyro-Plate' coating is heated, in a reducing atmosphere, to a minimum temperature of 1650°F. (900°C.) and the 'Pyro-Tung' to a minimum temperature of 2050°F. (1120°C.). Cooling to below 600°F. (315°C.), in the same atmosphere, completes the process.

The successful application of the two techniques to dies used by the Thermo-Form Company, Inc., and the Southern Bolt and Screw Company is described. Plough-steel dies coated by the 'Pyro-Plate' process are stated to be about a quarter of the cost of stainless-steel dies, and to have operated for over 1000 hours at 1000°F. (540°C.) with no sign of surface oxidation.

Press Forging of Cast '17-4 P.H.' and 18-8-type Stainless Steels

P. GOUWENS, T. WATMOUGH and J. BERRY: 'Application of Press-Forged Castings.'

Modern Castings, 1959, vol. 36, Oct., pp. 47–54.

The work described was carried out to evaluate the potential of a duplex process developed as a means of modifying the mechanical properties of high-strength cast materials so as to combine the economic advantages offered by casting methods with the technical benefits of cold-working.

The first stage in the process entails the production, by conventional quality foundry techniques, of a casting of such dimensions that subsequent deformation by forging will result in a finished part of correct shape and size (i.e., a casting corresponding, in forging parlance, to the last-stage forging blank). The casting is then austenitised or solution-treated prior to press forging. Forging is carried out isothermally at temperatures which will beneficially influence certain structural factors (e.g., orientation, size and distribution of martensite and precipitation-hardening nuclei), but below those at which recrystallisation occurs. Specific advantages obtainable by the process are: (1) Higher ultimate tensile strengths (up to ultra-high strength levels), compared with those of heat-treated castings of the same

* A casting alloy of the following composition: chromium 11–14, aluminium 5·5–6·5, iron 5 max., molybdenum 3·5–5·5, niobium/tantalum 1–3, manganese 1·0 max., titanium 0·25–1·25, silicon 1·0 max., carbon 0·2 max., sulphur 0·015 max., per cent., remainder nickel.

composition. (2) Corresponding increases in yield and proof strength, with less loss of ductility than that usually associated with strengthening by heat-treatment alone. (3) Relative freedom from the marked directionality effects exhibited by most forgings. (4) Higher resistance to impact and fatigue at normal temperatures. (5) Lower lead time and costs for short-run or prototype parts than are associated with forgings.

In the present paper the techniques and problems involved in the process are discussed in relation to data derived from its application to the fabrication of '17-4 P.H.' and 18-8 (Type 347) chromium-nickel stainless steels.

Machining of 'Nimonic' Alloys and Ultra-High-Tensile Steels

G. A. STREETS: 'Machining Nimonic.'
Machinery (Lond.), 1959, vol. 95, Sept. 30, pp. 633-8.

The machining of ultra-high-tensile steels and the heat-resisting nickel-base alloys involves problems which, due to the density and highly abrasive characteristics of both materials, their extreme resistance to the cutting action, and their tendency to work-harden, are very similar. Certain differences exist, however, and it is emphasised that, though the information presented in this article is generally applicable to the ultra-high-tensile steels, the data and comments relate specifically to the 'Nimonic' series of alloys.

One of the most common methods of machining these materials is by milling, the practical aspects of which are outlined in sections concerned with the selection of tool materials, the use of appropriate tool geometry, choice and use of the most suitable cutting fluid, cutting methods, and milling speeds and feeds (milling speeds are given for the 75, 80, 80A, 90, 95, 100 and 105 grades of the 'Nimonic' series). Optimum procedures for grinding, broaching and drilling the 'Nimonics' are discussed (with data on broaching speeds and chip loads), and the article includes brief notes on spark erosion, electro-polishing and bench work.

Effects of Radiation on the Properties of Ferrous Materials

D. E. THOMAS: 'Radiation Damage in Ferrous Metals.'
Jnl. of Metals, 1959, vol. 11, Aug., pp. 523-7.

In this review the author makes no attempt to present an exhaustive recapitulation of the literature: his aim is rather to give, by selection of illustrative data, an overall picture of the behaviour of iron and steel under radiation.

The literature reviewed (relating to mechanisms of radiation damage, and to radiation damage in iron, carbon steel and stainless steels) leads the author to the following conclusions:

'In ferrous materials, as in other metals and alloys, irradiation increases strength and decreases ductility. In general, the yield stress is increased proportionately more than the ultimate stress, accompanied by a reduced strain-hardening capacity and decreased uniform elongation. In the stainless steels there appears to be no cause for alarm, in that the property changes generally appear to saturate at a total exposure of 10^{19} or 10^{20} nvt. In the carbon steels, the rise in ductile-brittle transition temperature and the loss of elongation and reduction-in-area are of concern, and further work in extending the data to higher neutron exposures, particularly at elevated irradiation temperatures, is required in order to provide a basis for the use of these steels in the more severe applications.

'There is an absence of in-pile creep data for steels. However, this does not appear to pose a problem since in-pile creep studies on several other materials indicate that the creep rate is reduced, as might be anticipated from the general nature of the effects on strength properties.

'Irradiation-induced structural changes in steels have received little attention thus far. Structural effects observed in non-ferrous systems and in fissionable materials strongly suggest that such effects might be found in ferrous materials, particularly in those which are irradiated in a non-equilibrium condition at the temperature of irradiation.'

Factors Influencing Stress-Corrosion Cracking of Stainless Steel

W. B. BROOKS: 'Stress-Corrosion Cracking of Austenitic Stainless Steels.'
Corrosion, 1959, vol. 15, Sept., pp. 103, 106, 108, 110.

The author, after reviewing, in the introduction to the paper, the characteristic features of, and the factors which contribute to, stress-corrosion cracking of 18-8-type chromium-nickel austenitic steels, explores various approaches to the problem which might form a basis for preventive action or fruitful research.

In a discussion of the design of heat-exchanger equipment for use with chloride-containing waters, attention is drawn to the advantages of tube-side rather than shell-side cooling, to the necessity of eliminating any possibility of stagnation, and to the reduced risk of cracking associated with operating conditions which result in full water boxes. Water velocities should be maintained at a minimum of 5 ft./sec. (1·5 m./sec.), while insulation containing chlorides should be protected from moisture, and the temperature of the water should be as low as possible. Satisfactory aeration is essential, and recirculating water should contain no chromates or other oxidising compounds. The pH of the environment, though not critical, is nevertheless important. Reference is made also to cases of stress-corrosion cracking which originated in intergranular corrosion of the steel.

In the second part of the paper, which is concerned with the theoretical aspects of stress corrosion, the author considers the rôles played by plastic deformation, hydrogen, the composition of the steel, and the behaviour of the surface film. Alloying additions

of nickel are considered to increase resistance to stress-corrosion cracking, and are suggested as an avenue of fruitful investigation. The nature of the corrosion phenomenon (involving such complex factors as film formation, adsorption effects, and electrical double layers) are mentioned as fields in which study should also prove rewarding.

Inhibition of Chloride Stress Corrosion of Stainless Steel

J. H. PHILLIPS and W. J. SINGLEY: 'Screening Tests of Inhibitors to Prevent Chloride Stress Corrosion.' *Corrosion*, 1959, vol. 15, Sept., pp. 450t–4t.

The advent of pressurised-water nuclear power plant has resulted in intensified research to develop some means of preventing the occurrence of stress corrosion in the numerous austenitic stainless-steel equipment exposed to the hot chloride-containing water. The work now described was initiated to determine the feasibility of achieving this aim by modification of the water environment, and, in particular, to discover an inhibitor or water treatment which would prevent stress corrosion of a niobium-stabilised 18-8-type chromium-nickel stainless steel (A.I.S.I. Type 347).

The programme involved three phases:

(1) Screening tests on inhibitors selected from the following groups: oxygen scavengers; complexing agents; film-forming and neutralising compounds; additives known to inhibit localised corrosion; additives intended to minimise general corrosion.

(2) An extensive evaluation, under various test conditions, of inhibitors selected for further investigation on the basis of the results obtained in phase (1). The variables studied included the chloride concentration (which ranged from 50–500 p.p.m.), the phosphate concentration (100–300 p.p.m.), the pH (which was varied in the range 10·6–11·2), the oxygen content of the environment, and the concentration and combination of the inhibiting additions.

(3) The relative efficacy of the most promising inhibitors was assessed by tests conducted in model boilers. The results of this phase of the study will be published on completion of the work involved.

U-specimens of the steel were exposed to each of the test environments, at 500°F. (260°C.), in a tilting autoclave which was cycled between an upright and inverted position once every 5 minutes for 24 hours. After exposure the specimens were examined metallographically for signs of stress-corrosion cracking and to assess the efficacy of the inhibitors.

The results of phases (1) and (2) are considered to warrant the following conclusions:

'1. Sodium nitrate appears to inhibit chloride stress-corrosion attack of Type 347 stainless steel, in tilting autoclave tests, if the mole ratio of nitrate to chloride used is at least unity and the pH of the solution containing chloride is higher than about 10·5.

'2. Chloride stress-corrosion attack of austenitic stainless steel can be prevented, at least in tilting autoclave tests, by exclusion of oxygen. If properly applied, sodium sulphite can be employed as the oxygen-scavenging agent.

'3. Combination of sulphite and nitrate appears superior to either inhibitor alone, at least under the conditions of the tilting autoclave test.

'4. Sodium nitrate and sodium sulphite should be investigated further in model-boiler tests for application in prevention of chloride stress-corrosion attack in austenitic stainless-steel-tubed steam generators.

'Although the work reported in this article is limited to Phases 1 and 2 of the inhibitor programme, it is considered important to report that in three shell-and-tube model-boiler tests (Phase 3) with sodium nitrate, cracking has been found on Type 347 stainless tubing in all boilers in the tube-to-tube sheet crevice area. The apparent discrepancy between model-boiler test results and tilting-autoclave test results with nitrate has not been resolved. Additional model-boiler tests are now in progress, or contemplated, to investigate sodium sulphite and the combination of sodium sulphite and sodium nitrate.'

Corrosion-Resistance of Nickel-containing Aluminium Alloys

W. E. TRAGERT: 'The Diffusion of Corrosion Hydrogen in Aluminium Alloys.'

Jnl. Electrochemical Soc., 1959, vol. 106, Oct., pp. 903–4.

It has been proposed (see, for example, reference to papers by DRALEY and RUTHER in *Nickel Bulletin*, vol. 29) that the resistance of an aluminium alloy containing 1 per cent. nickel ('X-8001') to catastrophic corrosion in high-temperature water is due to the presence, at the surface of the alloy, of Al_3Ni particles which function as cathodic sites for evolution of corrosion-product hydrogen and hence inhibit penetration of hydrogen into the aluminium. The experiments described were designed to determine the validity of this hypothesis.

Cans, fabricated from an aluminium alloy (aluminium 99·45 min. per cent.) and 'X-8001' and containing distilled water, were sealed, and heated in an autoclave to 300°C. The autoclave atmosphere was then analysed for water and hydrogen. The data obtained indicated that corrosion hydrogen diffused through both alloys. Alloy 'X-8001' was relatively uncorroded, whereas the nickel-free alloy was extensively oxidised: according to the galvanic-protection hypothesis, the proton flux should have produced accelerated oxidation of both alloys. The author therefore concludes that the second-phase particles in alloy 'X-8001', rather than functioning as local cathodes, serve, on oxidation, to alter the nature of the corrosion-product film and render it less permeable to the diffusing reactants. Although the concentration of hydrogen in the oxide film and basis metal may exert an influence on the reaction kinetics, this effect is considered of secondary importance relative to the rate-controlling mechanism.

Polishing and Buffing of Nickel-containing Materials

L. F. SPENCER: 'Fundamental Considerations in Polishing and Buffing.'

Metal Finishing, 1959, vol. 57, Sept., pp. 60–7.

In this review the author is concerned with the economic and technical considerations involved in the selection of a particular polishing and buffing technique for production of a desired surface finish (i.e., a lustrous, satin, matt or scratch-brush finish) on materials of commercial interest.

The ingredients of the polishing or buffing compound, including both the binder and abrasive employed, are important factors, while the effect of a particular abrasive binder is usually governed by the method used to apply it to the wheel, by the rate of drying and by the adhesion obtained. The influence of the type, size and speed of the wheel is indicated by the fact that as many as fourteen finishes can be produced by varying these variables (the types of wheel available include felt, walrus-hide, pocketed, sewed-muslin, loose-muslin, packed-loose-muslin, and string). The optimum pressure for a specific combination of buffing or polishing conditions can be determined only by experimentation. In the first part of the article each of these factors is discussed in general terms in sections relating to polishing and buffing operations.

The finishing procedure used for a specific metallic material will depend on the type of metal in question, the degree to which it has been formed prior to finishing and the forming method used, the condition of the surface, and the finish required. In the second part of the article the author suggests procedures suitable for use with aluminium and aluminium-base alloys, magnesium alloys, copper and copper-base alloys, nickel and nickel-base alloys, stainless steels and electroplated materials.

Welding of 'Nimonic' Alloys

R. LEVICK and P. A. MORGAN: 'Welding 'Nimonic' Heat-Resisting Alloys for Gas-Turbine Assemblies.'

HENRY WIGGIN AND CO., LTD., *Publn.* 1122, Nov. 1959; 19 pp.

Reprint from *Aircraft Production*, 1959, vol. 21, July, pp. 251–7: see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 7, p. 237.

Welding of 'Hastelloy B', 'Hastelloy N' ('INOR 8') and 'Hastelloy W'

G. M. SLAUGHTER, P. PATRIARCA and R. E. CLAUSING: 'Welding of Nickel-Molybdenum Alloys.'

Welding Jnl., 1959, vol. 38, Oct., pp. 393s–400s.

In view of their strength and excellent resistance to corrosion by fused salts at service temperatures in the range 1200°–1300°F. (650°–705°C.), nickel-molybdenum-base alloys have been evaluated at the Oak Ridge National Laboratory in relation to their possible use as structural materials in nuclear-reactor systems utilising molten fluoride salts as fluid fuels. Work on 'Hastelloy B' and 'Hastelloy W' revealed, however, that age-hardening in the relevant temperature range caused significant embrittlement, and that oxidation-resistance was inadequate (see abstract of report by KENNEDY and DOUGLAS in *Nickel Bulletin*, 1959, vol. 32, No. 9–10, pp. 295–6). Subsequently an extensive programme carried out to develop a non-age-hardenable high-strength nickel-molybdenum alloy with the necessary corrosion- and oxidation-resistance resulted in the development of 'INOR 8', now commercially available as 'Hastelloy N' (see abstracts in *Nickel Bulletin*, 1959, vol. 32, No. 3, pp. 85–6; *ibid.*, No. 6, p. 186). The work now reported was initiated to study the weldability of 'Hastelloy B', 'Hastelloy W' and 'INOR 8'.

Tensile, hardness and metallographic specimens were machined from weld metal deposited in the grooves of test plates. To study the ageing characteristics of 'Hastelloy B' and 'Hastelloy C' weld metal, a correlation was made between the room-temperature hardness and the microstructures resulting from ageing for various times at various temperatures. Welds of 'INOR-8' were included in this study for comparative purposes. Tensile properties were determined at room-temperature and 1200°F. (650°C.), using specimens in the as-welded and welded-and-aged conditions. Welding and testing procedures are described and data obtained from the test programme are summarised in graphical form.

The authors' findings are quoted below:

'1. The commercially available nickel-molybdenum 'Hastelloy Alloy B' and the nickel-molybdenum-chromium alloy 'Hastelloy Alloy W' are readily weldable by the inert-gas-shielded tungsten-arc process and exhibit no difficulties with regard to cracking and porosity. The room- and elevated-temperature properties of weld metal in the as-welded condition are adequate for molten-salt reactor service.

'2. Hardness studies indicate that 'Hastelloy Alloy B' weldments (weld metal and base - metal plate) are subject to significant age-hardening during service in the temperature range 1100°–1500°F. (595°–815°C.), with the greatest hardening noted at 1300°F. (705°C.). The effect of ageing at 1200°F. (650°C.) was studied extensively and was found to increase the room- and elevated-temperature tensile strength of weld metal, while severely decreasing the ductility.

'3. An increased hardening in the base metal of 'Hastelloy Alloy B' weldments adjacent to the weld was attributed to the influence of residual stresses from the welding operation.

'4. The precipitate observed in 'Hastelloy Alloy B' welds and base plate after ageing at 1300°F. (705°C.) and below has been tentatively identified as the beta phase of the binary nickel-molybdenum phase diagram, while that at 1500°F. (815°C.) has been tentatively identified as the gamma phase.

'5. 'Hastelloy Alloy W' weld metal is also subject to age-hardening at elevated temperatures, but to

a lesser extent at 1200°F. (650°C.) than 'Hastelloy Alloy B'. Age-hardening raises its room- and elevated-temperature tensile strength and decreases its ductility significantly. The hardening at 1200°F. (650°C.) is attributed to a submicroscopic precipitate.

'6. A non-age-hardenable nickel-molybdenum-chromium alloy, which was developed by the O.R.N.L. Metallurgy Division and designated as 'INOR-8', is readily weldable. The weld metal possesses acceptable mechanical properties at room temperature and at 1200°F. (650°C.). This alloy is now commercially available.'

Fusion Welding of Precipitation-Hardening Stainless Steels

R. MEREDITH: 'Fusion Welding Precipitation-Hardening Steels.'

Welding Jnl., 1959, vol. 38, Oct., pp. 963–8.

In this article the author gives details of the procedures employed, by the Missile Division of North American Aviation, to fusion weld '17-7 P.H.' stainless-steel sheet and '17-4 P.H.' fittings used in the fabrication of large liquid-tight missile assemblies.

The size of the assemblies and the thin-gauge material used precluded the possibility of heat-treatment after fabrication, and the '17-7 P.H.' material was therefore welded in the hardened condition (particulars of heat-treatment are given). The article includes notes on the preliminary tests which were carried out to determine welding techniques and the welding characteristics of the two materials. Curves are presented summarising the design criteria established for welded joints and indicating the strength of offset welds and the influence of grinding on weld strength. The results of design experiments in which pressure vessels welded from '17-7 P.H.' steel were tested to destruction are noted, and brief particulars are given of the automatic welding and other equipment used in fabricating the components.

From the point of view of weldability the precipitation-hardenable materials are considered to be superior to the high-strength steels previously used in aeronautical structural applications.

Binders bearing the date 195- and suitable for 1959 Nickel Bulletins are now available.
We shall be pleased to send one free of charge.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

INDEXES TO ITEMS IN

NICKEL BULLETIN, 1959, VOLUME 32

		pages
1.	Subject Index	379–390
2.	Corrigenda	391
3.	Trade Names referred to in Volume 32 ..	392–393
4.	Author Index (technical abstracts)	394–396
5.	,, ,, (patent abstracts)	397

SUBJECT INDEX TO VOLUME 32

The Index comprises a consolidated list of titles of abstracts, compiled from the sectional contents lists of the individual issues.

Within the Sections normally used (**GENERAL, NICKEL, ELECTRODEPOSITION**, etc.), the items are broadly classified in appropriate sub-sections, within which they are, in most cases, entered in the order of their appearance in the Bulletin. The only exceptions to such order are (1) the grouping of the page numbers of serial items and of items of closely related subject matter, and (2) the alphabetical order used in the **GENERAL** and in the **HEAT- AND CORROSION RESISTING MATERIALS: Uses** Sections.

The **Leading Articles** referred to below, although listed separately, are shown also in the appropriate sub-sections in which such articles are differentiated from abstracts by an asterisk at the beginning of the entries.

A list of **Trade-Named Materials and Processes** referred to in this volume appears on pages 392-3.

LEADING ARTICLES

PHYSICAL AND MECHANICAL PROPERTIES OF SOME NICKEL-CONTAINING CORROSION-RESISTING STEELS 104-5

MOND CARBONYL-NICKEL POWDERS 137

GENERAL

(See also **General** and **Testing** Sub-sections of other Sections.)

Analytical Chemistry in the Field of Atomic Energy 138
Bright Annealing 71
Cermets: Production, Properties, etc. 65
: Bonding to Metals 38, 69
Diffusion in Metallic Materials 37, 138
Electrical and Thermal Resistivities of Metallic Materials 138
Grain Size: Significance, Determination, etc. 1
Hardness-Conversion Tables 37
Inert-Gas Consumable-Electrode Welding of Thin Materials 71
Investment Casting 170, 186, 223, 263, 359, 366
Metallographic Examination: Recommended Procedures 171
Oxidation of Nickel-containing Materials: Literature Review 138
Physical Properties of Metals and Alloys: Reviews 170, 231
Powder Metals: Production, Properties, etc. 65
: Glossary of Terms 37
: Production of Structural Parts 169
Precipitation from Solid Solution: Educational Lectures 245
Safety Discs 69
Spring Materials 170
Structure of Metals: Current Concepts 209
Testing at Elevated Temperatures: Creep and Stress-Rupture 170, 330
: Proof Stress 138
: Short-Time Tensile 170
Thermal Conductivity: Measurement, etc. 2, 209
Vacuum-Induction Melting 138
(See also **HEAT- AND CORROSION-RESISTING MATERIALS: Production**)
Zone Refining 169

NICKEL

Analysis and Determination

Determination by Solvent Extraction 6
Colorimetric Determination 6, 172
Gravimetric Separation of Copper, Nickel and Zinc 6
Determination in Sodium 39
„ „ Cast Iron 72
„ „ Brasses and Bronzes 80, 180
Ion-Exchange Procedure 107
Determination in Uranium 107
Analysis of Metals used in Nuclear-Power Plant 138
Determination of Cobalt in Nickel 151
„ „ Nickel in Nickel-Gold Alloys 172
Removal of Zinc from Ammoniacal Nickel Solution 172
Determination of Sulphur in Nickel Electrodeposits 177
„ „ Nickel in Ferrites 182
„ „ „ „ Cobalt and Cobalt Salts 211
Spectrophotometric Determination of Cobalt, Nickel, Copper 211
Titration of Metal Acetates in Glacial Acetic Acid 249
Photometric Determination of Nickel in Copper-Nickel 250
Determination by Extraction with Coloured Cations 250
„ of Nickel in Stainless Steels: Fluorescent X-Ray Analysis 276
Magnetometric Titration of Nickel 280

Nickel-Clad Materials: *see* **HEAT- AND CORROSION-RESISTING MATERIALS: Clad, Faced and Lined Materials**

Composition, Properties and **Structure**

(For Influence of Irradiation on Properties, *see* **HEAT- AND CORROSION-RESISTING MATERIALS: Properties,** and **Uses**

Thermal Conductivity 2, 170
Elastic Modulus 4
Diffusion in Nickel and Other Metals 4, 37, 138

	Page
Oxidation and Scaling	5, 106, 138, 368
Effect of Rapid Heating on Properties	19
Compatibility with Graphite at Elevated Temperatures	20
Resistance to Liquid Sodium	24
Hardness: Conversion Tables	37
High-Purity Nickel *ex* U.S. Bureau of Mines	38
Specific Heat	38, 170
Corrosion by Sulphuric Acid	39
Anodic Behaviour in relation to Composition	40, 353
Forms of Nickel for Alloying in Steel	48
Bursting Temperature for Safety Discs	69, 70
Graphitically Embrittled Nickel: Recovery	71
Resistance to Hydrochloric Acid, Hydrogen Chloride and Chlorine	89
Passivity Characteristics: Symposium	89 (See also 40, 353)
Ductility: Effect of Creep Strain	106
Creep Properties	106, 210, 230, 264, 349, 368
Magnetization: Effect of Pressure	107
Magnetostriction and Anisotropy in	107, 149
Physical Properties Relevant to Heat Transfer	170
Trace Elements in Nickel: Effect on Properties	171
Internal Ferromagnetic Resonance	172
Electrical Resistance of Sputtered Films	178 (see also 322)
Structure of Metals: Monograph	209
Influence on Beer	210
Resistance to Hydrogen Fluoride	237
Modulus of Rigidity	246
Thermoelectric Stability at Elevated Temperatures	267
Optical Properties	279
Solubility in Beryllium	279
Mechanical Properties	283
Corrosion-Resistance *vis-a-vis* Titanium, Zirconium and other Materials	309
Corrosion-Resistance in Tall-Oil Processing	309
Cathode Nickel for Electron Tubes: Composition	321
Electrical Resistivity	322
Strain-Hardening and Softening: Effect of Chromium	322
Recrystallization of	349

Occurrence, Extraction and Refining

High-Purity Nickel produced by U.S. Bureau of Mines	38
Zone Refining of Nickel	169
Refining of Nickel from American Ores	171
Extraction from Sudbury Ores	209
,, of Nickel and Cobalt: Bibliography	245
Refining of Nickel-Cobalt-Copper Ores: Sherritt-Gordon Methods	245
,, ,, Lateritic Ores: Nicaro Process	246, 279
Falconbridge Nickel Mines: History	279

Powder Production, Properties and Uses

(For Nickel and Nickel-Alloy Binders in Cermets, *see* **HEAT- AND CORROSION-RESISTING MATERIALS: Powder Production**)

Terms used in Powder Metallurgy	37
Production and Properties of Nickel Powders: Symposia and Reviews	65, 169
Direct Rolling of Strip from Powder	72, 210
Ground Nickel Powder: Structure	73
*Mond Carbonyl-Nickel Powders	137
Sintering of Tungsten: Nickel and Cobalt Additions	247
Gas Desorption from Powders	280
Carbonyl-Nickel Powder for Cathodes of Electron Tubes	321

Processing (see also **Occurrence, Extraction and Refining,** and **Welding**)

Thermal Regeneration of Oxidized Nickel	5
Recovery Treatment for Graphitically Embrittled Nickel	71
Production of Strip by Direct Rolling of Powder	72, 210
Zone-Refining Treatment	169
Machining: Recommended Practice	181
Fabrication of Tubing	181
Pickling and Acid Dipping	216
Cold Drawing and Annealing: Influence on Rigidity	246
Nickel for Electron Tubes: Processing Technique	321
Thin Foils: Processing for Examination	343
Annealing: Recrystallization Behaviour	349
Polishing and Buffing	376

Specifications and Testing (see also **GENERAL**)

A.S.T.M. Specifications	3
Rapid-Heating Test Methods	19
Hardness Conversion Tables	37
Creep/Ductility Test Methods	106
B.S. Specifications	139, 269
Metallographic Examination	171

Uses (see also **Powder Production and Uses**)

For Uses in Atomic-Power Plant *see* **HEAT- AND CORROSION RESISTING MATERIALS: Uses**

Storage Batteries	6, 247, 349
Heat-Transfer Equipment in Aerothermal Conditions	54
Chemical-Process Industries, General	69, 70, 95, 181
Bursting Discs	69, 70
In Coinage	44, 79, 172, 355
,, Fuel Cells	173
,, Catalysts	173, 280
,, HF Alkylation Units	237
,, Butane-Isomerization Plant	237
,, Electron Tubes	246, 321
,, Vehicles (see also **ELECTRODEPOSITION**)	258
,, Thermocouples	267

Welding

For Chemical Plant	95
Of Tubing	181
Fusion Welding	326
Ultrasonic Welding	338
Welding to Dissimilar Materials	338, 344

Nickel Salts and Compounds
(See also **ELECTRODEPOSITION**)

Nickel Compounds in Storage Batteries: *see* **Uses**

Nickel Oxide in Ferrites: *see* **NICKEL-IRON ALLOYS: Magnetic Properties**

Nickel/Nickel-Chloride System	4
Nickel Oxide: Sintering Properties	5, 210

Page

Photochemical Properties of Nickel Compounds 39
Nickel-Oxide Sinter for Use in Steelmaking 48
Nickel Salts for Plating: D.I.N. Specification 73
Nickel Oxide: Thermal Conductivity 170
Nickel Chloride for Treatment of Wheat Rust 173, 248
Nickel Fluoride: Literature Survey 248
Nickel Oxide: Conversion to Metal: *see* **Occurrence, Extraction and Refining**
Nickel Oxide: Interaction with Methane 280

ELECTRODEPOSITION AND OTHER COATING METHODS

(See also **HEAT- AND CORROSION-RESISTING MATERIALS: Clad, Faced and Lined Materials**)

Analysis of Solutions

Determination of Additives 75, 141
Analysis of Sulphamate Solutions 108
Determination of Sulphur in Nickel Deposits 177

Electrodeposition of Alloys

Tin-Nickel and other Tin-base Alloys 9, 142
Molybdenum and Molybdenum Alloys 11, 145
Copper-Nickel Alloys 141, 354
Tungsten Alloys 145
Bronze Alloys 142, 303
Nickel-Cobalt and Nickel-Iron Alloys: Pyrophosphate Solutions 176
Nickel-Zinc and Nickel-Thallium Alloys 214
Chromium Alloys: Literature Review 324

Electrodeposition of Nickel, and Properties of Electrodeposited Nickel

Black Nickel Plating 7, 144
Barrel-Plating Techniques 7
Stress in Coatings 8, 42, 107, 141, 214, 355
Porosity in Coatings (see also Quality of Coatings, below) 8 (corrig. 165); 108, 143, 282, 283, 323
Plating of Typewriter Parts 8
„ „ Automobile Hub Caps 8
On Zinc-base Alloys 9, 251, 350
Quality of Nickel/Chromium Coatings: Influence of Chromium and of Underlay 10, 42, 43, 77, 145, 146, 197, 213, 251, 303, 324, 350, 352
Anodic Behaviour of Nickel in Plating Solutions 40, 353
Nickel-Plating Solutions: Review 41
'Kraq-o-lite' Patterned Plating 41, 110
Corrosion-Resistance: *see* Quality of Coatings, above
Nickel-plated Parts for Heat-Transfer in Aerothermal Conditions 54
Nickel Salts for Electroplating: Purity 73
Brightening and Levelling Agents and Techniques 73, 177, 281
Sulphate-Oxalate Electrolytes 75
Structure of Electrodeposited Nickel 75, 282, 353
Distribution of Deposits : Effect of Base 75
Plating of Titanium, Zirconium, Niobium, Tantalum, Molybdenum, Tungsten 78, 175
Resistance of Coatings to Detergents 94
Sulphamate Solutions 107, 108, 141

Page

Bright Nickel Plating: Influence of Age of Electrolyte 140
Nickel Plating of High-Strength Steel: *See* **CONSTRUCTIONAL STEELS: Properties**
Purity of Water used for Electrolytes 144
Nickel and Nickel/Chromium Underlays to Evaporated Aluminium Films 147
Handbook on Nickel Plating 174
Co-deposition of Nickel and Hydrogen 174, 214
Sulphur in Electrodeposited Nickel 177
Fundamental Research in Nickel Plating 211
Plating of Thorium 211
Magnesium-Salt Additions to Electrolytes 212
Nickel Undercoat in Gold-Plating of Molybdenum 215
Engineering Applications of Nickel Plating 215
Nickel-plated Leads for Electron Tubes 246
History of Nickel Plating 250
Pyrophosphate Electrolytes 251
Automatic Addition of Chemicals to Electrolytes 281
Roughness in Deposits 282, 354
Orientation of Deposits: Influence of Chloride 282
Plating of Magnesium Alloys 283
Coatings on Molybdenum 297, 336, 365 (See also 215)
Deposits from High-Chloride Solutions 322
Fatty-Acid Films on Basis Metal 323
Hardness of Deposits: Influence of Wetting Agents 323
Chlorides, Copper, Calcium and Iron: Influence on Deposits 354
Manganese: Influence on Deposits 355

General

Plating of High-Strength Steels: *see* **CONSTRUCTIONAL STEELS, Properties**
Stripping Electrodeposited Coating 43
Electrodeposition of Palladium and Platinum 140
Iron and Chromium Deposits on Copper Single Crystals 143
Electrodeposition of Rhodium 144
Silver Anodes 144
Handbook on Nickel Plating 174
Automatic Addition of Chemicals to Electrolytes 281
Polishing and Buffing Methods 376

Other Coating Methods

(See also **HEAT- AND CORROSION-RESISTING MATERIALS: Clad, Faced and Lined Materials**)

'Composite Electrochemical Materials': Carbide/Metal Composites 10
Evaporated Nickel-Chromium Films 11
'Kraq-o-lite' (Silicated-Nickel) Process 41, 110
Electroless Plating
Properties and Uses of 'Kanigen' Plating 78
Appraisal of Process 78
Plating of Carbon 144
Handbook on Nickel Plating 174
Addition of Metal Salts to Solutions 212
Undercoatings for Cadmium Plating of Stainless Steel 273
Nickel-Phosphorus Alloy for Brazing Stainless Steel 275
Ceramic Coatings on Nickel-Chromium Alloys 115
Enamelling: Effect of Nickel Flash 109
Anodizing of Aluminium 140
Deposition of Nickel viâ the Carbonyl 141, 252
Paint and Plastic Coatings 144, 302

Page

Evaporated Aluminium Films: Nickel and Nickel/Chromium Underlays 147
Protective Coatings on Molybdenum: *see* **HEAT- AND CORROSION-RESISTING MATERIALS: Properties**
Coating of Stainless Steel to Enhance Wear-Resistance in Nitrogen 301
Coatings to Resist Atmospheric Corrosion: Review 303

Specifications and Testing

A.S.T.M. Specifications for Electrodeposited Coatings 40
Accelerated *vs.* Weathering Tests 43, 109, 146, 251, 302, 323, 350
Thickness of Coatings: Specifications and Tests 43, 79, 177, 213, 214, 251, 302, 350, 351
Nickel Salts for Plating: D.I.N. Specification 73
Porosity: Methods of Measuring 108, 143, 282, 283, 323
Optical Examination of Surfaces and Films 143, 144
Reactions during Chemical Polishing: Methods of Study 144
Nickel/Chromium Coatings: Dutch Specification 174
Brenner and Senderoff Contractometer: Modified Form 214
Nickel-plated Leads for Electron Tubes: Specification 246
B.S. Specifications for Electrodeposited Nickel and Chromium 350
B.N.F. Plating Gauge 351

NON-FERROUS ALLOYS

(See also **HEAT- AND CORROSION-RESISTING MATERIALS**)

Analysis
(See also **NICKEL: Analysis and Determination**)

Gravimetric Separation of Copper, Nickel and Zinc 6
Analysis of Brasses and Bronzes 80, 180
„ „ Alloys used Nuclear-Power Plant 138
Nickel-Gold Alloys: Determination of Nickel 172
Corrosion Products on Copper Alloys: Identification 195
Spectrophotometric Determination of Cobalt, Nickel and Copper 211
Copper-Nickel Alloys: Photometric Determination of Nickel 250

Composition, Constitution and Structure

Grain Size: Significance. Determination 1
Diffusion in Alloys 4, 37, 138, 253
Nickel-Manganese Alloys: Effect of Deformation on Structure 11
Ti_2Ni: Compositional Range 13 (see also 110, 185)
Nickel Alloys for Alloying in Steel 48
(Cobalt)-Nickel-Chromium Alloys: Structure/Magnetic Properties 80
Nickel-Titanium and Nickel-Titanium-Carbon Alloys 110, 185
Nickel-Cobalt-base Alloys of High Damping Capacity 117, 227
Nickel-Aluminium Bronze for Propellers 148
Wrought Cupro-Nickels: Data Sheet 177
Structure of Metals: Monograph 209
Nickel-Copper-Germanium Alloys 216

Page

Ternary Carbides of Nickel with Germanium and Indium 216
Precipitation from Solid Solution: Symposium 245
Solubility of Nickel in Beryllium 279
Copper-Nickel-Manganese Constitutional Diagram 283
Copper-Beryllium Alloys: Effect of Other Elements 325
Nickel-Cobalt Alloy: Recrystallization of 325
Copper-Nickel Alloys: Heats of Formation 325
Nickel-containing Gunmetals: 356
Nickel-Tin Bronze Alloys 356
Influence of Lead in Bronzes and Gunmetals 356

Plating
(See also **HEAT- AND CORROSION-RESISTING MATERIALS: Clad, Faced and Lined Materials**)

„ Molybdenum: *See* **HEAT- AND CORROSION-RESISTING MATERIALS: Properties**
Of Zinc-base Alloys 9, 40, 251, 350
„ Copper-base Alloys 40, 350
„ Magnesium Alloys 283

Powder Production, Properties and Uses

Production of Structural Parts by Powder Metallurgy: Symposium 169
Sintering of Tungsten: Influence of Nickel Addition 247
Sintered Nickel Silver Components 326

Production and Processing

Zinc-base Die Castings: Polishing 9 (see also 40, 350)
Bright Annealing: Furnaces and Atmospheres 71
Processing of Monel Roofing 111, 181
Vacuum-Induction Melting: *See* **HEAT AND CORROSION-RESISTING MATERIALS: Production**
Nickel-Aluminium-Bronze Propellers 148
Zone Refining 169
Wrought Cupro-Nickels: Data Sheet 177
Machining Nickel Alloys 181
Fabrication of Nickel-Alloy Tube and Pipe 181
Pickling and Acid Dipping 216
Cold-Drawing and Annealing: Influence on Rigidity 246
Nickel Silver Spectacle-Frame Wires 253
Founding of Nickel-containing Gunmetals 356
Age-Hardening of Nickel-Tin Bronzes 356
Polishing and Buffing 376

Properties (See also **Specifications**)

Thermal Conductivity 2, 170
Elastic Modulus of Nickel-Copper Alloys 4
Nickel-Chromium Evaporated Films: Physical Properties 11
Nickel-Manganese Alloys: Magnetic Properties 11
Spontaneous Magnetization in Nickel-Copper Alloys 12
Rapid Heating: Effect on Properties 19
Intergranular Cavitation in Stressed Copper-Nickel Alloys 12
Compatibility with Graphite at Elevated Temperatures 20
Behaviour in Wet Oxygenated Steam 21
Corrosion by Hydrofluoric Acid 25
Hardness: Conversion Tables 37
Bursting Pressures of 'Monel' Safety Discs 69, 70

Page

Non-Magnetic Copper-Nickel Alloy 79
Magnetic Properties of (Cobalt)-Nickel-Chromium Alloys 80
Alloys Resistant to Hydrochloric Acid, etc. 89, 237
Magnetization of Nickel-Copper Alloys: Effect of Pressure 107
Heat Capacity of Low-Chromium Nickel-Chromium Alloys 110
Of Monel Roofing 111, 181
Nickel-Cobalt-base Alloys: Damping Capacity 117, 227
: Oxidation 180
: Plasticity 215
: Creep of Single Crystals 349
Oxidation of Nickel Alloys: Literature Review 138
Nickel-Aluminium-Bronze Propellers: Service Records 148
Magnetostriction and Anisotropy of Single Crystals 149
Spring Materials 170
Wrought Cupro-Nickels: Data Sheet 177
'Monel' Alloys and Nickel-Zirconium Alloys: Physical Properties 170
Specific Heat at Low Temperatures: Copper-Nickel Alloys 178
Alloys used in Marine Engineering in U.S.A. 178
Electrical Resistance of Metal Films 178
,, Conductivity of Cast Copper Alloys 179
Gold-Nickel Alloys: Ageing Reactions 179
Wear- and Gall-Resistant Nickel-Copper-Silicon Alloys 180
Nickel-Alloy Tubing 181
Cavitation-Erosion Resistance of 'Monel' 231
Modulus of Rigidity of 'Monel' and Copper-Nickel Alloy 246
Thermoelectric Stability of Nickel-Copper Alloy at Elevated Temperature 267
Mechanical Properties of 'Monel' 283
Corrosion-Resistance of Condenser-Tube Alloys 299
Magnesium Alloys containing Nickel: Resistance to Sea Water 308
Corrosion in Sour-Water Stripping Units 308
Nickel-containing Gunmetals 356
Nickel-Tin-Bronze Sand Castings 356

Specifications and Testing
(See also **Plating**)

Thermal Conductivity: Measurement 2, 209
Specifications for Nickel Alloys 3, 43, 139, 269
Rapid-Heating Tests 19, 293
Hardness Testing: Conversion Tables 37
Metallographic Examination 171
Wear- and Galling-Resistant Nickel-Copper Alloys: Specification 180
'Monel' Roofing: Data Sheet 181
Nickel-Alloy Tubing: Specifications 181
Leads of Electron Tubes: ,, 246
Tungsten-Nickel-Copper Alloy: ,, 254
Welding of Non-Ferrous Alloys: ,, 326
Non-Ferrous Bourdon Tubing: ,, 328

Uses (See also **Properties,** and **Specifications**)

For Uses in Atomic Power Plant, *see* **HEAT- AND CORROSION-RESISTING MATERIALS: Uses**

Coinage 44, 79, 172, 355
Rivets 48
In Petroleum Equipment 59, 236

Page

Bursting Discs 69, 70
Non-Magnetic Alloy for Instrumentation 79
Nickel-Magnesium Alloy for Treatment of Steel 82
Chemical Plant (General) 95, 181, 236, 237, 299, 308
Roofing 111, 181
Marine Propellers 148, 178
Springs 170
Cupro-Nickels: Review of Uses 177
In Marine Engineering: Review 178
Wires for Spectacle Frames 253
Thermocouples 267
Condenser Tubes 299
Soluble Plugs in Sea Water 308

Welding, Brazing and Soldering

Joining of 'Zircaloy' to itself and to Stainless Steel 61, 199, 311, 338
,, ,, Dissimilar Metals 61, 203, 274, 338, 344
Of Nickel-Aluminium-Bronze Propellers 148
,, Nickel Alloys: Recommended Procedure 95, 181
,, Cupro-Nickel Alloys 177
,, Nickel-Alloy Tubing 181
,, Copper to Stainless Steel 203
Fusion Welding of Non-Ferrous Alloys: Current Stage of Development 326

NICKEL-IRON ALLOYS

Analysis

Of Permanent-Magnet Alloys 107, 231
,, Ferrites 182

Composition, Constitution, Structure and Properties (*excluding* **Magnetic Properties,** *q.v.*)

Thermal Conductivity 2
Metallographic Examination 17
Solubility of Nitrogen in 39
Martensite Transformation 46, 47
Oxidation Characteristics 111
Spring Alloys 170, 284
Directory of Nickel-Iron-base Alloys 182
Brazing of Graphite to 'Nilo K' 284
Welding to Dissimilar Materials 338, 344

Magnetic Properties and Uses of Magnetic Alloys

Non-Linear Magnetics and Magnetic Amplifiers: Conference 44
Powders: Production, Properties, Uses: Symposium 65
Permanent-Magnet Materials: Stability 80, 149
Magnetic Properties/Temperature Relationships 80, 81, 149, 284, 357
Reversible Permeability: Influence of Mode of Demagnetisation 81
Magnetization: Effect of Hydrostatic Pressure 107
Core Materials 148, 357
Anisotropy and Magnetostriction in Single Crystals 149
Directory of Nickel-Iron Alloys 182
Magnetic Alloys: A.I.E.E. Symposium 216
: Review Data 284

Page

Films in Digital Computers 254
Tape produced by Powder Metallurgy 254
Magnetic Properties: Handbook 357
Magnetic Annealing 358

CAST IRON

General

Grain-Size: Estimation and Significance 1
Erosion and Corrosion in Wet Oxygenated Steam 21
Chill Casting of Ni-Hard Rolls 47
Absorptiometric Analysis of 72
'Ni-Resist'
Properties and Applications: Handbook 112
Oxidation-Resistance 112
Elevated-Temperature Properties 182, 217
Cavitation-Erosion Resistance 231
Resistance to Hydrochloric Acid 237
Austenitic Cast Irons: Specifications 255, 284
In Sour-Water Stripping Plant 308
„ Tall-Oil-processing Plant 309
Growth-, Scaling- and Oxidation-Resistance 112, 150
Purification by Oxidation 150
Cast Irons for Die Blocks 150
Growth and Scaling Tests 150
Metallographic Examination of 171
Elevated-Temperature Properties: Summary 182, 217
Thermal and Elastic Properties of Irons used in Diesel Engines 217
'Ni-Hard' for Grinding Equipment 218, 285, 358
Vibration during Solidification 254
Welding 286

Spheroidal-Graphite Cast Iron

Ductile 'Ni-Resist' : in Oxygenated Steam 21
: Properties and Applications 112
: Oxidation-Resistance 112
Purification by Oxidation 150
Irons for Die Blocks 150
Growth and Scaling Tests 150
Elevated-Temperature Properties 182
Thermal and Elastic Properties of Irons used in Marine Diesel Engines 217
Applications in Steelworks 219
Vibration during Solidification 254
Welding 286

CONSTRUCTIONAL STEELS

Analysis
(See also **NICKEL: Analysis and Determination**)

Determination of Cobalt 151
„ „ Titanium, Zirconium, Niobium and Tantalum 185

Composition, Constitution and Structure
(See also **Specifications**)

For Influence of Composition on Properties of Welds, *see* **Welding**
Forms of Nickel available for Alloying in Steel 48

Page

Steels Deoxidized and Desulphurized with Nickel-Magnesium 82
Influence of Microstructure on Fatigue 112
High-Speed-Tool Steels containing Nickel 113, 185
Ultra-High-Strength Steels: Compositions, etc. *See* **Properties**
Precipitation from Solid Solution: Educational Lectures 245
Steels Vibrated during Solidification: Structure 254
Rotor Forgings: Structure as affected by Composition 256
Temper Embrittlement: *See* **Properties**
Leaded Free-Machining Steels 328
Control of Austenite Grain Size 361

Plating

Cadmium Plating: Effect on Properties, Improved Techniques, etc. 14, 142, 151, 222, 259, 273, 327 (see also 182)
A.S.T.M. Specifications for Electroplated Coatings 40
Effect of Shot Peening prior to Chromium Plating 48
Nickel Plating of High-Tensile Steel 107
Plating of Ultra-High-Tensile Steels: General Notes 182
Nickel- and Chromium-Plating: B.S. Specification 350

Powder Production

Production of Structural Parts from Powders: Symposium 169

Production and Processing
(See also **Plating, Powder Production** and **Welding**)

Peening prior to Plating 48
Nickel for Alloying in Steel: Forms available 48
Bright Annealing 71
Deoxidation and Desulphurization with Nickel-Magnesium 82
Heat-Treatment of Nickel-containing Steels 113, 182, 183
Investment Casting 170
Treatment of Pressure-Vessel Steels 184
Ultra-High-Tensile Steels: Processing 182, 218, 219, 220, 360, 374
Forging and Forgeability: Literature Survey 222
: Effect of Small Reductions on Properties 360
Deformation prior to Transformation 183
Pickling and Acid Dipping 216
Vibration during Solidification 254
Rotor Forgings: Processing of 256
Rolling: Effect of Composition on Spread 256
Nickel-Chromium-Molybdenum Steel Castings: Processing 286
Hot-Cold Working 327
Machining of Lead-containing Steels 328
Investment Casting 359
Ingot Cracking, etc., in relation to Austenite Grain Size 361

Properties and Uses
(See also **Specifications**)

For Uses in Atomic Power Plant *see* **HEAT- AND CORROSION-RESISTING MATERIALS: Uses**

Plating of High-Strength Steels: Effect on Properties 14, 48, 108, 142, 151, 183, 222, 259, 327

Page

Erosion and Corrosion in Oxygenated Steam 21
Corrosion by Liquid Sodium 24
„ „ Hydrofluoric Acid 25
Chromium-plated Steel Shot-peened before Plating 48
Steels used in Petroleum Equipment 58, 59, 196
Bursting Discs 69
Nickel-Copper-Phosphorus Steels:
Resistance to Sea Water 82
Ultra-High-Strength Steels:
Fatigue 112, 286, 359
'300-M' Steel 182
Classification and Evaluation 219
For Aeronautical Applications: Symposium 220, 224
Crack Propagation in 257, 259, 287 326
Low-Temperature Properties 287
Alloy-Steel Castings 288, 359
Rapid Heating: Effect on Properties 293
Elevated-Temperature Properties of Cast and Wrought Types 359
Effect of Hot-Cold Working 327
Solidification Conditions and Structure; Effect on Properties 360
9% Nickel Steel for Low-Temperature Service 112
Nickel-containing High-Speed-Tool Steels 113, 185
Compressive, Tensile, Bearing and Shear Properties at Elevated Temperatures 153, 294
Underwater Corrosion in Tropical Regions 160
Deformation prior to Transformation, to Improve Properties 183
Pressure-Vessel Steels 184
Steel for Welded Bridge Construction 185
Forging : Literature Survey 222
: Effect of Small Reductions on Properties 360
Rotor Forgings: Properties 256
Stress-Cycling: Influence on Mechanical Properties 256, 258
Temper Embrittlement: Microstructural Study 257
: Influence of Niobium 258
: Effect on Fatigue 258
: Literature Review 359
: Internal Friction and Brittleness 359
Use in Vehicles 258
Creep: Effect of Environment
See **HEAT- AND CORROSION-RESISTING MATERIALS: Properties**
Impact-Transition Temperature:
Influence of Specimen Form 287
Gear Steels for High-Speed Aircraft 288
Materials for High-Temperature Service: Comparison 290
Materials used in Steam Plant:
Effect of Service Conditions 298, 372
Corrosion of Constructional Steels:
B.I.S.R.A. Report 302
Corrosion by Fumes, Sea Spray and Moisture 303
Brittle Fracture of Forging Steels: Effect of Cracks 326
Machinability of Lead-containing Steels 328
Stress-Corrosion Cracking in Oil-Production Equipment 341
Effects of Radiation on Steels 374

Specifications and Testing
(See also **GENERAL**)

Weldability Tests 15, 205, 328, 329, 361
Hardness Testing: Conversion Tables 37
Testing at Elevated Temperatures
Proof-Stress: Specification 138
Short-Time Tensile and Creep-Rupture 170, 330

Page

Metallographic Examination 171
High-Strength Steels: Test Methods 220
Hot-Twist Test for Forgeability 222
Crack-Propagation Tests 257, 259, 287
(see also Weldability Tests)
Corrosion Testing: B.I.S.R.A. Report 302
Stress-Corrosion Testing 341
Investment Castings in Carbon and Low-Alloy Steels: Specification 359
Grain-Size Determination: Tests 361
(see also 1)

Welding

Cracking in High-Tensile Steel Welds 15, 182, 205, 289, 328, 329, 361
Inert-Gas Consumable-Electrode for Welding Thin Material 71
Welding 9% Nickel Steel 113
„ Carbon and Low-Alloy Steels to Dissimilar Materials 96, 113, 311, 312, 314, 344
Welded Bridge Construction 185
Low-Hydrogen Electrodes: Review 361

HEAT- AND CORROSION-RESISTING MATERIALS

Analysis and Identification

Identification of Chromium-Manganese-Nickel and Chromium-Nickel Steels 99
Determination of Aluminium in High-Temperature Alloys 124
„ „ Cobalt in Stainless Steels 151
Analysis of Nimonic Alloys 151
Determination of Titanium, Zirconium, Niobium, Tantalum, in Stainless Steels 185
Analysis of Corrosion Products on Copper Alloys 195
Sigma Phase: Methods of Identification 224
Identification of Phases: Electron Metallography 224
Determination of Copper in Stainless Steels 231
„ „ Iron, Chromium, Nickel, by Fluorescent X-Ray Analysis 276

Clad, Faced and Lined Materials, including **Sprayed Metals**
(See also **Welding**)

Rapid-Heating Tests of Clad Materials 19
Bonding with Adhesives 19
Stainless-Steel-Clad Steel in Sodium 24
'Inconel X' Sheathing of Space Aircraft 54
Nickel-Alloy Facings in the Petroleum Industry 59
'Brightray'-coated Exhaust Valves 88
Clad Steels, Liners and Overlays in Chemical Plant 96
Clad and Lined Digesters 96, 97
Cladding of Silver/Boron-Carbide Cermets 98
Ceramic Coating of Nickel-Chromium Alloys 115
Sandwich Panels 124, 191, 193
Clad Coatings on Molybdenum 158, 297, 336, 337, 365, 371
Cathodic Protection of Nickel-Lined Tanks 164
Colmonoy 'Sprayweld' Process 198
Clad Steels in Butane-Isomerization Plant 237
Nickel-Chromium-Boron Facing in Sugar Plant 310

Page
Hard Facings: Production, Properties, Uses 310
Graded and Clad Cermets: Nickel-Alloy Cladding 364
Coating of Hot-Work Dies 373

Composition, Constitution and Structure

Nickel-Titanium Alloys 13, 110, 185
Precipitation Phenomena in Nickel-base Alloys 16, 49, 115, 151, 153, 185, 224, 233, 245, 260, 290, 292, 333, 362, 363
Boron and Zirconium in High-Temperature Materials 16, 17, 170, 261, 263, 268, 367, 370
Structural Changes on Rapid Heating 19
„ „ during Creep Testing 49, 113, 335
Nickel-Chromium-Molybdenum-Iron Alloys: Structure 49, 85, 152, 186
'Nicrotung' and 'D.C.M.' Cast Alloys: Composition 53
High-Alloy Castings: Compositions, U.S. Standards 55
'D.319' Austenitic Steel: Composition 55
Lithium in Austenitic Steels 56
(Cobalt)-Nickel-Chromium Alloys: Structure, Addition Elements, etc. 80, 335
Sigma Phase
Nature, Occurrence, Effects 83, 123, 224, 232, 303, 304
Structural Changes on Deformation of Stainless Steel 86
Nickel-Chromium-Cobalt-base Alloys: Recrystallization 86
Electrical-Resistance Materials: Compositions 87, 88
'D-979' Alloy: Composition 115
Nickel-Cobalt Alloys of High-Damping Capacity 117, 227
Solubility of Nitrogen in Austenitic Steels 118
„ „ Hydrogen „ „ „ 194
Stabilizing Elements in Stainless Steels and Alloys: Influence on Precipitation and Properties 119, 292
Diffusion in Metals and Alloys:
Literature Review 138
Iron in Nickel-base Alloys 253
'Nimonic' Alloys: Textbook 151
'Unitemp 212' Precipitation-Hardenable Steel 155
Chromium-Manganese-Nickel and Chromium-Nickel Steels: Comparison 161, 193, 269
Dispersion Hardening in Nickel-base Alloys 185, 366
'Hastelloy-N': Composition 186
Nickel-Aluminium-base Alloys 187, 228, 365
Cast Nickel-Chromium-Iron Alloys: Alloy Casting Institute 'H' series 187
'A.M. 350' and 'A.M. 355' Steels 188
'PH 15-7-Mo' Steel 188
Structure of Metals: Monograph 209
Ultra-High-Strength Stainless Steels: Classification, etc. 219
Investment-Cast High-Nickel Alloys: *See* **Properties** 223
Precipitation-Hardening Casting Steels: 'P.H.-55' series 223
Cast Nickel-Chromium Alloys: Molybdenum Additions 225
'Inconel': Recrystallization and Grain-Growth 226
Nickel-Molybdenum-base Alloys: Modified Composition to Prevent Intercrystalline Corrosion on Welding 233
Precipitation from Solid Solution: Symposium 245
Retained Austenite in Precipitation-Hardening Stainless Steels 260
Chi Phase in Iron-Chromium-Nickel-Titanium Alloys 260
Alloys for Operation at 980°C.: Experimental Compositions 263
Hot-worked Structure: Effect on Creep 264
Uranium or Thorium in Stainless Steel 268
Precipitation in Stainless Steels: Effect on Intergranular Corrosion 270, 271
Strengthening of Nickel- and Cobalt-base Alloys: Solid-solution, carbide- and precipitation-hardening 290
Nickel-Chromium Alloys: Effect of Minor Elements on Structure 292
'Hastelloy B' and 'Hastelloy W' 295
Corrosion of Stainless Steels: Influence of Structure *See* **Properties**
Dislocations in Stainless Steels 300
Low-Temperature Stability of Stainless Steels 301
Controlled-Transformation Stainless Steels: Summary 331
Structure in Relation to Thermal Stability of Hardened Stainless Steels 333
'Inconel X' and 'Incoloy 901': Phase Changes in 335
K State in Nickel-Chromium-base Alloys 336
Deep Drawing: Structural Changes produced by 341
Thin Foils of Steels and Alloys: Structure 343
Single Crystals of Stainless Steel 343
Magnetic Phases in Stainless Steels 343 (see also 301)
Nickel-base Alloys: Review of Status and Future 362
Nickel-Chromium-Iron-Cobalt-base Alloys for Service at 955°C. 362
Cobalt-base Alloys: Review 363
„ „ Casting Alloy 'M.L. 1700' 363
Secondary Phases in High-Temperature Alloys 363
Chromium-base Alloys: Review 365, 368
Molybdenum and Molybdenum Alloys: Review 365, 366
Directional Grain Structure: Effect on Creep-Rupture 370

General

Design of Stainless-Steel Extrusions 165
Cavitation-Erosion: Mechanism 231
Gas Lubrication at High Temperatures 266
Symposium on High-Temperature Materials 362 *et seq*

Plating (For Plating of Cermets, *see* **Powder Production**)

Nickel-plated Structures for Resistance to Thermodynamic Heating 54
Oxidation-Resistant Coatings for Molybdenum 158, 215, 297, 336, 337, 365, 366, 368, 369, 371
Cadmium Plating of Stainless Steel 273
Plated Stainless Steel in contact with Liquid Nitrogen 301
Nickel- and Chromium-Plating of Stainless Steel 350

Powder Production: Properties and Uses of Powder-produced Materials

Terms used in Powder Metallurgy 37
Bonding of Cermets to Metals 38, 69, 98, 363
Production and Processing of Powders and Cermets: Symposia 65, 169
Dispersion-Hardenable Nickel-base and other Alloys 86, 185, 332, 366
Cladding of Cermets with Stainless Steel 98
Nickel-Aluminium-base Alloys 187, 228, 365
Nickel/Titanium-Carbide Cermets 229, 334, 363, 364
High-Temperature Intermetallic Materials: Evaluation of Types 266
Powder Materials: Potential Uses in High-Temperature Service 331
Slip Casting of Stainless Steels 342
Cermets: Problems involved in Development 363

Page

Wettability and Microstructural Study of Liquid-Phase Sintering 364
Cermet Turbine Blading 365
Ceramic-coated Alloys: Spectral Emittance 369

Production and Processing

High-Temperature Ageing of 'Inconel X' 16
Vacuum-Melting and -Casting 17, 82, 115, 138, 187, 335, 362, 363, 366, 367
Nickel: Forms for Alloying 48
Machining of Stainless-Steel Rotor Blades 48
Fabrication of Sheet in 'Nimonic' Alloys and Stainless Steel 52
Processing 'Nicrotung' and 'D.C.M.' 52
Processing of Cast Alloys 'Nicrotung' and 'D.C.M.' 53
Bright-Annealing Stainless Steel 71
High-Temperature Deformation of Austenitic Steel: Equicohesive Temperature 86
Softening Treatments for Stainless Steel 104
Processing Monel Roofing 111, 181
Heat-Treatment of 'D.979' and 'A.F. 71' Alloys 115
,, ,, ,, 'Nimonic' Alloys 116, 151, 229
Centrispinning High-Temperature Materials 117
Nitrogen Solubility as Production Factor for Stainless Steel 118
Machining of 'Nimonic' Alloys 151, 374
Heat-Treatment of 'Unitemp 212' Precipitation-Hardening Steel 155
'Inconel X': Processing for Aircraft Use 159
Nickel-Molybdenum Alloys: Heat-Treatment 159, 233
Cleaning, Pickling and Passivation of Stainless Steels 162, 197, 216, 310, 342
Extrusion of Stainless Steel 165
Investment Casting of Steels and Alloys 170, 186, 223, 263, 366
Fabrication of High-Nickel Alloys: Recommended Practice 181
,, ,, Cast Nickel-Chromium-Iron Alloys 187
Heat-Treatment and Mechanical Working of 'A.M. 350' and 'A.M. 355' 188
Fabrication of Bolts in 'A-286' 189
Precipitation-Hardening Cast Steels 223
Post-Fabrication Heat-Treatment of Sheet and Tube Materials 229
Rolling: Influence of Composition on Spread 256
Hot-Working of Nickel and 'A-286': Effect on Creep 264
Strengthening Treatments for Nickel- and Cobalt-base Alloys: Solid solution, carbide and precipitation hardening 290
Pre-Straining: Effect on Fatigue 292
Cold Working: Effect on Structure and Properties of Nickel-Chromium Alloys 295
Sensitization Treatments for Stainless Steels: TTT Curves 304
Controlled-Transformation Treatments for Stainless Steel 331
Processing Molybdenum and its Alloys 337, 366
Deep Drawing of Stainless Steels: Frictional Effects 341
Thin Foils: Processing for Examination 343
Single Crystals of Stainless Steel: Production of 343
Nickel-base Alloys: Improved Techniques 362
Chromium and Chromium-base Alloys: Improved Techniques 365
Surface Treatment: Effect on Spectral Emittance 369
Press Forging: 'Inconel 713C' Dies 372
: Plated Dies 373
: Press-Forged Castings 373
Polishing and Buffing Procedures 376

Page

Properties

A. Corrosion- and Oxidation-Resistance

Effect of Environment on Creep-Rupture and other Properties 18, 88, 106, 230, 265, 295, 302, 368
Compatibility with Graphite at Elevated Temperatures 20
Erosion and Corrosion in Steam 21, 298
Cast Iron: Corrosion- and Oxidation-Resistance 21, 112, 150, 231, 237, 255, 284, 308, 309
Intergranular Corrosion in Austenitic Steels (See also Stress-Corrosion, below)
Not associated with Carbide Precipitation 22
In Petroleum Refineries 91
Effect of Stabilizing Additions 119
,, ,, Sigma Phase 232
Of Nickel-Molybdenum Alloys on Welding 233
Effect of Prolonged High-Temperature Exposure 270, 372
,, ,, Precipitation Reactions 270, 271
Apparatus for Testing Susceptibility 272
Of Weldments in Types 304 and 304L Steels 273
,, ,, ,, 316 and 316L 274
Time/Temperature/Sensitization Curves 304
Inter-relation of Intergranular Cracking and Stress-Corrosion Cracking 374
Stress Corrosion of Austenitic Steels
In Lithium Hydroxide 23, 306
,, Chlorides 56, 305, 374, 375
Of Autoclave Components 57
In Dilute Caustic Solutions 92, 298, 299
,, Hydrochloric-Acid Cleaning Solutions 162
Effect of Notches 340
In Oil-Production Equipment 341
Factors affecting Cracking 374
Cathodic Protection by Applied E.M.F. 23, 164
Corrosion by Liquid Sodium 24, 271
,, ,, Hydrofluoric Acid, and Fluorine 25, 236
,, ,, Hydrochloric Acid, Hydrogen Chloride and Chlorine 50, 56, 89, 162, 271, 305
Scaling of Nickel-Chromium Alloys 51, 369
Corrosion by Hydrogen Sulphide and Other Corrodents in Petroleum-Refining and Allied Industries 57, 59, 91, 164, 196, 198, 235, 237, 309, 341
,, ,, Oil Ash (in Gas Turbines) 88, 195, 227, 339, 340
,, ,, Molten Lead: Inhibition by Nickel and Zirconium Additions 89
Passivity in Metals: Colloquium 89
Pitting Corrosion in Stainless Steels 90, 234, 271, 272, 309
Underground Corrosion: Review 91
Corrosion by Nitric Acid
Titanium-Stabilized Steels 92
High-Alloy Steels with and without Stabilizers 120
Attack by Nitric Acid in Presence of Chlorides 121
Huey Test: Critical Discussion 122
Corrosion by Acid-contaminated Cooling Water 93
,, ,, Detergents 94
Corrosion- and Oxidation-Resistance of Stainless Steels: Review 118
Oxidation of Metals: Literature Review 138
,, -Resistance of 'Nimonic' Alloys 151
Corrosion by Boron Oxide 156
Oxidation Characteristics of Austenitic Steels 157
,, of Molybdenum and its Alloys: Protective Measures 158, 215, 297, 336, 337, 365, 366, 368, 369, 371
Nickel-Molybdenum-Iron Alloys: Corrosion as affected by Heat-Treatment 159

Page
Underwater Corrosion in Tropical Regions 160
Comparative Corrosion-Resistance of Chromium-Nickel and Chromium-Manganese-Nickel Steels 161, 269
Corrosion by Nitric/Hydrofluoric Acid Solutions 163
,, ,, Acids: Evaluation by Three Tests 163
,, ,, Hot Gaseous Environments 187
,, ,, Sea Water 188
Oxidation-Resistance of Typical High-Temperature Alloys 190
Corrosion by Hydrogen Peroxide 197
,, of Automobile Components (see also ELECTRODEPOSITION) 197
Corrosion-Resistance of Precipitation-Hardening Cast Steels 223
Internal Oxidation in Nickel-Chromium Alloys 227
Oxidation-Resistance of Cobalt- and Nickel-base Alloys, etc. 227
(see also 362 *et seq.*)
Corrosion under Heat-Flux Conditions 230
Cavitation-Erosion Attack 231
Oxidation of Stainless Steels in Aqueous Media: Kinetics of 235
Corrosion in Uranium-Refining Plant 236
,, by Gas Lubricants 266
,, in Steam Plant 298, 299
Wear-Resistance in Liquid Nitrogen 302
Resistance to Atmospheric and to Chemical Corrosion: Reviews 303
Corrosion of Stainless Steel: Effect of Structure 303
,, by Phosphoric Acid 307
Nickel-containing Aluminium Alloys in Hot Water 307, 375
Nickel- or Iron-containing Magnesium Alloys in Seawater 308
Corrosion in Sour-Water Stripping Plant 309
Corrosion-Resistance in Chemical Plant: Titanium, Zirconium, Nickel-base Alloys 309
Properties required in Materials for Reactors 339
Stress-Corrosion Cracking in Copper Alloys 341
Corrosion-Resistance of Passivated Surfaces 342
Symposium on Properties of High-Temperature Materials 362 *et seq.*
(including items relating to Oxidation, e.g. Oxidation of Molybdenum, Oxide Growth on Nickel-Chromium Alloys, etc.)

B. Mechanical and Physical Properties

Thermal Conductivity 2, 209
Of 'Nichrome' Films 11
Of Alloys containing Boron and/or Zirconium 16, 17, 170, 261, 263, 268, 367, 370
Of Vacuum-Melted Alloys 17, 82, 115, 138, 187, 335, 362, 363, 366, 367
Creep-Rupture and Other Properties; Effect of Environment 18, 106, 230, 265, 295, 302, 368
Of High-Chromium Steels: Summary 18
Rapid Heating: Effect on Properties 19, 293
Thermal Fatigue and Related Properties 51, 230, 257, 262, 297
Of Cast Alloys 'Nicrotung' and 'D.C.M.' 53
Nickel-plated Structures for Resistance to Thermodynamic Heating 54
Of 'D-319' Nickel-Chromium-Molybdenum Steel 55
,, Austenitic Steels containing Lithium 56
Safety Discs: Bursting Pressures 69, 70
Magnetic Properties of (Cobalt)-Nickel-Chromium Alloys 80
Page
Creep-Resistance of Austenitic Steels: Comprehensive Study 83
Fatigue, Creep, etc., of Nickel-base Alloys: Russian Research 84
Creep Properties of Nickel-Molybdenum-Chromium-Iron Alloys 85, 152
Electrical-Resistance Materials: Properties and Design Data 87
,, ,, ,, Increase of Life in Nitrogen 88
Elastic Modulus of Austenitic Steel 89
Physical and Mechanical Properties of Stainless Steels 104
Heat Capacity of Nickel-Chromium Alloys 110
Cast Irons: High-Temperature Properties 112, 150, 182, 217, 231, 255, 284
Creep-Rupture Strength of Austenitic Steel Sheet and Bar 114
Ceramic Coatings: Effect on Creep 115
Of 'D-979' and 'AF 71' Alloys 115
Combined Static and Dynamic Stress: Effect on Properties 115
'Nimonic' Alloys: Typical Properties 116, 151, 229
Effect of Irradiation on Steels and Alloys 116, 302, 339, 374
High-Damping-Capacity Cobalt-Nickel-base Alloys 117, 227
Of Centrispun Parts 117
Stainless Steels: Review 118
Nitrogen Porosity of Stainless Steels 119
Tensile, Compressive, Bearing and Shear Properties of Aircraft Materials 153, 294
Of 'Unitemp 212' Precipitation-Hardenable Steel 155
,, Nickel-Molybdenum-Iron Alloys: Effect of Heat-Treatment 159
,, Spring Materials 170
(see also 116)
,, Investment-Cast Materials 170, 186, 223, 263, 366
Physical Properties relevant to Heat Transfer 170
Of Nickel-Alloy Tube and Pipe 181
,, 'Hastelloy N' 186
,, Nickel-Aluminium-base Alloys: *See* **Powder Production**
,, Cast Heat-Resisting Alloys of A.C.I. 'H' Series 187
,, 'A.M. 350' and 'A.M. 355' Hardenable Steels 188
,, 'P.H. 15-7 Mo' Steel 188, 294
,, Bolts in 'A-286' 189
Creep and Stress-Rupture: Extrapolation of Data 189, 261
Ductility of 'Inconel' Alloys: Effect of Welding Cycle 190
(see also 296)
Of Chromium-Nickel and Chromium-Manganese-Nickel Steels: Comparison 193, 194, 269
Of Sandwich Panels and Honeycomb Structures *See* **Clad, Faced and Lined Materials**
Creep of Nickel: *See* **NICKEL: Properties**
Low-Temperature Properties of Austenitic Steels 195, 196, 287, 301
Ultra-High-Strength Stainless Steels: Classification 219
(see also entries relating to individual hardenable steels)
Precipitation-Hardenable Cast Steels: 'P.H. 55' series 223
Of Materials for Rockets and Missiles 224
,, 'M-252' Blading Alloy 225
,, Cast Nickel-Chromium Alloys: Effect of Molybdenum 225
Post-Fabrication Treatment for Improvement of Properties 229
Emissivity Characteristics of Metals and Alloys 231, 369

Page

Specific Heat of Stainless Steel 231
Crack Propagation in High-Strength Stainless Steels 257, 265
Creep of 'A-286' : Effect of Hot Working 264
Effect of Notches on Creep Strength 265
Thermocouple Materials: Thermoelectric Stability 267
Of Materials for High-Temperature Service: Critical Comparison 290, 331
,, Nickel- and Cobalt-base Alloys Strengthened by Various Means 290
High-Temperature Fatigue: Influence of Pre-Stressing 292
Of Nickel-Chromium Alloys: Influence of Cold Working 295
,, 'Hastelloy B': Influence of Thermal Cycle involved in Welding 296 (see also 190)
,, Steels used in Steam Plant 298
Spectral Reflectivity and Solar Absorptivity 299
Magnetic Properties as Criteria of Low-Temperature Stability 301
Wear-Resistance in Nitrogen Atmosphere 302
Of Controlled-Transformation Stainless Steels: Review 331
Nickel and Nickel-Chromium Dispersion-Hardened with Al_2O_3 332, 333
Thermal Stability of Precipitation- and Dispersion-Hardened Materials 333
Hot Hardness of Nickel-Chromium Alloys 334
Fatigue, Creep, etc., of 'Udimet 500', 'Hastelloy R-235' and 'GMR-235' 334
Creep-Resistance of Nickel-Copper Alloys 334
Elastic Limit of Cobalt-Nickel-Chromium-base Alloys 335
Internal Friction in Nickel-Chromium-base Alloys 336
Austenitic Steels for Reactors: Review 339
Symposium on High-Temperature Materials 362 *et seq.*
Cobalt- and Nickel-base Alloys: Review 362
Nickel-Chromium-Cobalt-Iron-base Alloys: Effect of Addition Elements 362
'Guy Alloy' for Turbine Blading 362
'W-545' Disc Alloy 363
Cobalt-base Alloys : Review 363
,, ,, Casting Alloy for Turbine Blading ('ML 1700') 363
Properties in Relation to Secondary Phases 363
Chromium-base Alloys 365, 368
Molybdenum and Molybdenum Alloys: 365, 366, 368, 369
Tungsten, Tantalum, Niobium, Rhenium 366, 369
Dispersion-Hardened Materials 366
Vacuum-Melted and Investment-Cast Materials 366, 367
Effect of Environment: Summaries 368
Fatigue of Typical High-Temperature Alloys 370
Properties in Relation to Directional Grain Structure 370
Creep of Austenitic Steels containing Molybdenum 371
Superheater Tubing after Long Service 372

Specifications

For Nickel Alloys: U.S. 3, 43
: British 139, 269
Stainless Steels: U.S. 55
High-Alloy Cast Materials: U.S. Classifications 55
D-319': Chromium-Nickel-Molybdenum Stee 55
Chromium-Nickel-Steel Castings for Nuclear Applications: U.S. 57
Stainless-Steel Tubing: Internal-Pressure Limits 95
*Stainless Steels: B.S., D.T.D. and A.I.S.I. 104

Page

'Nimonic' Alloys 151
Proof-Stress : Determination at Elevated Temperature: B.S. 138
Spring Materials: British 170
Short-Time High-Temperature Tensile and Creep Testing: A.S.T.M. 170
Metallographic Examination: A.S.T.M. 171
Nickel-Alloy Tube and Pipe: U.S. 181
Bolts and Screws of Age-Hardenable Stainless Steel: S.A.E./A.M.S. 189
Chromium-Manganese-Nickel Steel Bar: A.S.T.M. 194
Non-Magnetic Components in Ships: U.S. Proposals 194
Steels for Use with Concentrated Hydrogen Peroxide: British Defence Specification 197
Filler Wire for Welding Dissimilar Materials: S.A.E./A.M.S. 203, 204
Austenitic Cast Irons : A.S.T.M. and S.A.E./A.M.S. 255, 284
Nickel-Chromium-(Iron) Electrical-Resistance Alloys: A.S.T.M. and British 269
High-Expansion Nickel-Manganese Steel: S.A.E./A.M.S. 288
Vacuum-Melted Austenitic Steel: S.A.E./A.M.S. 290
Precipitation-Hardening Stainless Steel: S.A.E./A.M.S. 290
Vacuum-Melted Nickel-base Alloy: S.A.E./A.M.S. 290
Tubing for High-Temperature Fluid Transport: S.A.E./A.M.S. 297
Materials for Reactors, including Welding Procedure: U.S.A.E.C. Report 302
Stress-Rupture : Determination at Elevated Temperature : B.S. 330
Materials for Bourdon Tubing: B.S. 330

Testing

(See also **Analysis, Specifications**, and **GENERAL**)

Thermal-Conductivity Tests 2, 209
Rapid-Heating Test Methods 19, 293
Effect of Environment in Testing 18, 106, 230, 265, 295, 302, 368
Creep Testing: Structural Changes resulting from 49, 113, 335
Pitting-Corrosion Tests 90, 234, 271, 309
Corrosion Testing: Accelerated and Atmospheric Methods 92, 122, 163, 232, 233, 272, 302
Testing under Combined Static and Dynamic Stresses 115
Proof-Stress Testing at Elevated Temperature 138
Testing of 'Nimonic' Alloys 151
Oxidation Test Methods 158, 190
Short-Time Tension and Creep-Test Methods 170, 330
Metallographic Examination 171
Extrapolation of Creep and Stress-Rupture Data 189, 261
Ductility Testing of Welds 190
Oil-Ash Corrosion Tests: Synthetic Media used, etc. 195, 227, 339, 340
Identification of Corrosion Products on Copper Alloys 195
Welding Tests 205, 328, 377
Electron Metallography: Symposium 224
Thermal-Shock Tests 230
Corrosion under Heat-Flux Conditions: Apparatus and Technique 230
Specific Heat: Test Procedures 231
Cavitation-Erosion Testing 231
Cracking Tests, including Low-Blow Impact 257, 259, 287, 297
Aircraft Gas-Turbine Operation: Simulated Tests 262

Page

Gas-Lubrication Testing 266
Corrosion in Flowing Sodium: Test Procedure 271
'Vidigage' Thickness Tester 272
Fatigue Testing: Prot Test 292
Creep-Testing of Steam-Plant Materials 298
Stress-Corrosion Test Apparatus 305, 306, 341, 375
High-Temperature-Water Testing for Reactor Service 307
Passivation Tests for Stainless Steels 342
Electron Microscopy of Thin Foils 343
Determination of Magnetic Phases in Steels 343
Elevated-Temperature Tests for Cermets 363

Uses

Uses grouped in this sub-section are individually referred to in the **Properties** and **Specifications** sub-sections, in relation to the properties which render the materials suitable for the respective applications.

Aircraft (including Structural Uses, also Rockets and Missiles) 19, 48, 51, 54, 124, 144, 153, 159, 188, 190, 191, 193, 197, 200, 209, 219, 220, 221, 224, 231, 266, 286, 287, 288, 289, 290, 293, 294, 299, 301, 324, 362 *et seq.*, 369, 371, 377
Architecture 94, 111, 181, 303
Atomic Power Plant 20, 21, 23, 24, 25, 39, 57, 61, 85, 98, 107, 116, 121, 122, 138, 152, 163, 170, 186, 190, 199, 204, 209, 226, 229, 236, 248, 268, 271, 295, 296, 302, 305, 306, 307, 308, 311, 322, 339, 374, 375, 376
Bolts 189
Bourdon Tubing 330
Brazing Alloys 62, 199, 275
Bursting Discs 69, 70
Centrispun Parts 117
Chemical Plant (General) 69, 95, 96, 112, 164, 181, 303, 307, 309
Corn-Milling Plant 165
Dies 372, 373
Diesel-Engine Components 217
Domestic Hardware 94
Electrical-Resistance Materials 87, 88, 269
Electronic Equipment 11, 161, 215, 246, 321
Gas Turbines
  Aircraft 17, 52, 151, 200, 201, 225, 229, 262, 263, 266, 269, 290, 291, 293, 294, 297, 362 *et seq.*
  Industrial 20, 52, 53, 88, 89, 151, 195, 227, 269 339, 340, 362 *et seq.*
HF Alkylation Units 236
Non-Magnetic Applications 194
Petroleum and Related Industries 57, 58, 59, 91, 95, 164, 196, 198, 236, 237, 288, 300, 309, 341
Plugs (soluble) in Sea Water 308
Pulp, Paper and Cellulose-processing Plant 96, 97, 272, 308
Railway Engineering 165
Sandwich Structures: *see* **Clad, Faced and Lined Materials**
Springs 116, 170
Steam Plant, including Turbines and Heat Exchangers 60, 93, 96, 117, 227, 270, 298, 299, 305, 311, 312, 314, 371, 372
Sugar Plant 310
Surgical Apparatus 198
Thermocouples 267
Vehicles 258

Page

Welding, Brazing and Soldering, also **Cutting**
(See also **Clad, Faced and Lined Materials**)

Bonding with Heat-Resisting Adhesives 19
  ,, of Cermets to Metals 38, 69, 98
Welding and Brazing 'Nimonic' Alloys and Stainless Steel: Current Practice 52, 98, 104, 151, 237, 376
Nitrogen as Weld-backing Gas 60
Welded Tube Joints in Heat Exchangers 60
Welding to Dissimilar Metals 61, 96, 113, 203, 274, 311, 312, 314, 338, 344
Joining of 'Zircaloy' 61, 199, 311, 338
Nickel-Chromium-Boron and Gold-Nickel Brazing Alloys 62
Inert-Gas Consumable-Electrode Welding of Stainless Steel 71
Welding of High-Nickel Alloys for Chemical Plant 95
  ,, ,, Clad Steel and Liners 96
  ,, ,, Austenitic Steels: Recommended Practice 98, 104
  ,, ,, 'Inconel' Alloys 98, 190
Sigma Phase in Weld Metal 123, 203, 232
Brazing Stainless-Steel Sandwich Panels 124, 191, 193
Welding Nickel-Alloy Pipe and Tube 181
  ,, Precipitation-Hardening Steels 188, 237, 377
Effect of Welding Cycle on Ductility of Parent Metal 190, 296
Brazing Materials: Recent Developments: Palladium Alloys 199
Hydrogen Brazing 200
Wetting Reactions in Brazing 201
Joining Copper to Stainless Steel 203, 274
Welding Niobium-stabilized Steel 203
  ,, 'Inconel' for Nuclear Power Plant 204
Carbon Dioxide *vs.* Argon as Protective Gas 204
Hot-Cracking of Welds: Cast-Pin Tear Test 205
Nickel-Molybdenum-base Alloys: Prevention of Corrosion of Welded Material 233
Corrosion-Resistance of Welds
  Influence of Carbon Content 273
  Of Welds in Molybdenum-containing Stainless Steel 274
Nickel-Phosphorus (Electroless) Alloy for Brazing Stainless Steel 275
Welding of 'Hastelloy' Alloys 296
Welds in Nickel-Chromium-base Alloy: Properties 296
Welding of Materials for Nuclear Reactors 302
Molybdenum and Molybdenum Alloys: Brazing and Welding 338, 365
Ultrasonic Welding 338
Welded Austenitic Steels in Steam Plant 371
Welding of 'Hastelloy' and 'INOR' Alloys 376

Tungsten Arc Cutting of Stainless Steel 275

PATENTS 26, 125, 238, 315

ANALYSIS

See entries in **Analysis** sub-sections

Corrigenda to items in Volume 32

Page 8 Right-hand column, line 6.
For '*Metall*, 1957, vol. 11, pp. 166-7'
Read '*Metalloberflache*, 1957, vol. 11, pp. 366-7.

,, 71 Left-hand column, line 13.
For '*Metal Treatment*, 1958'
Read '*Metal Treatment*, 1959'

,, 94 Left-hand column, second item.
For *Schweizer Archiv*, 1958, vol. 24, Nov., pp. 335-70.
Read pp. 355-70.

,, 210 Left-hand column, first item.
After 'D. K. WORN' add 'and R. P. PERKS'

Page 230 Right-hand column: title of last item.
For '*Hot-Flux*'
Read '*Heat-Flux*'

,, 245 Left-hand column, line 1.
For 'GRITZLEN'
Read 'FRITZLEN'

,, 275 Left-hand column, line 2.
Delete 'to'

,, 294 Left-hand column: second item, first paragraph.
For '*Nickel Bulletin*, 1959, vol. 32, No. 5, p. 133'
Read '*Nickel Bulletin*, 1959, vol. 32, No. 5, p. 153'

TRADE-NAMES, MATERIALS AND PROCESSES

Referred to in Nickel Bulletin, Volume 32, 1959

16-25-6 Steel
See **Timken**
17-4 P.H. Steel } *See*
17-7 P.H. Steel } **Armco**
17-14 Cu-Mo Steel, 192.
17-22A(S) Steel
See **Timken**
19-9 DL Steel, 192, 363.
40N Cermet, 69.
300-M Steel, 183.
1040 Alloy, 149.
1079 Alloy, 153.
4750 Alloy, 149, 358.

A-286 Steel, 116, 189, 192, 193, 200, 264, 294, 367.
AF-71 Alloy, 115, 241.
Alfenol Alloys, 357.
Alnico Alloys, 67, 217.
Alnico I, II, III and **IV**, 284.
Alnico V, VI and **VII**, 149, 284.
Alnico XII, 284.
Alnicro, 20.
Aloyco 20 Steel, 60, 309.
Alphasil, 149.
Alumel, 156, 267.
AM-350 Steel, 188, 193, 231, 237, 287, 293, 299, 331, 338.
AM-355 Steel, 188, 193, 237.
Ampco 8, 309.
Ampco 18, 309.
Andyar Batteries, 247.
A Nickel
See **Nickel**
Armco 17-4 P.H., 373, 377.
Armco 17-7 P.H., 19, 31, 124, 189, 192, 193, 200, 287, 293, 294, 331, 338, 371, 377.
Armco P.H. 15-7 Mo, 188, 193, 294, 331.
Armex GT Electrode, 371.
ATV Steel, 86.
Audio Transformer A, 357.

Brightray Alloys
B.A.C. Brightray, 88.
Brightray B, 87, 269.
Brightray C, 87, 269.
Brightray F, 87.
Brightray H, 87.
Brightray S, 87, 269.
BTH Leaded Bronze, 21.

C-242 Alloy
See **Nimocast**
CA Alloy, 246.
Carpenter 20 Steel, 60, 163, 309.
CF-520 Chromium-Plating Solution, 324.
Chem-milling Process, 159.
Chlorimet 2, 55, 309.
Chlorimet 3, 55, 236, 309.
Chromel, 147, 156, 267.
Chro-Mow Steel, 293.
CM1 Cermet, 69.
Coast Metal 50, 192, 336.
Coast Metal 53, 608, 706 and **728**, 192.
Colmonoy Alloys
Colmonoy, 59.
Colmonoy 4, 198.
Colmonoy 5, 158, 198.
Colmonoy 6, 28, 31, 68, 158, 198.
Colmonoy 70, 198.
Colmonoy C, 336.
Complexone, 6.
Composite Electrochemical Materials (CEM), 10, 110.
Copnic, 267.
Corrodkote Accelerated-Corrosion Test, 10, 43, 145, 147, 252, 324.
Corronel B, 60, 89.
CR-110 Chromium-Plating Solution, 324.
Croloy Steels, 25.

D-319 Steel, 55.
D-979 Alloy, 115, 241.
DCM Alloy, 53.
Deltamax, 45, 81, 149, 284.
Duomelt Process, 155.
Duovac Process, 155.
Duranickel, 181, 237.
Durichlor, 236, 309.
Durimet 20 Steel, 60, 236.
Duriron, 236, 309.
Dynamax, 149.

Efco - Udylite 4 B1H Barrel-Plating Solution, 8.
Efco-Udylite No. 31 Plating Solution, 140.
Elinvar, 217.
EME Steel, 21.

Ferramic H and **H-1**, 149.
Ferry, 87, 269.
TC Ferry, 87.
F. Nickel
See **Nickel**
F.V. 520 Steel, 186, 331.
F.V. 548 Steel, 371.
F.V. 555 Steel, 371.

G-18B Steel, 83, 223, 370.
G-32 Steel, 370.
G-34 Steel, 223.
G-39 Steel, 223.
G-42B Steel, 28.
G-64 Casting Alloy, 69, 83.
Girbotol Process, 60.
GMR-235 Alloy, 83, 223, 334, 363, 366, 367.
GMR-235D Alloy, 116.
G Nickel
See **Nickel**
Gunite, 309.
Guy Alloy, 17, 83, 154, 263, 335, 362, 363, 366.

Hastelloy Alloys, 68, 164.
Hastelloy A, 237.
Hastelloy B, 55, 60, 85, 163, 186, 209, 230, 237, 295, 296, 299, 302, 303, 376.
Hastelloy C, 55, 60, 163, 165, 209, 236, 267, 302, 309, 338, 369.
Hastelloy D, 60, 309.
Hastelloy F, 309.
Hastelloy N, 186.
Hastelloy R-235, 191, 209, 231, 267, 297, 334.
Hastelloy W, 191, 295, 312, 376.
Hastelloy X, 363.
Haynes Stellite Alloys (*See also* **Hastelloy**)
Stellite 1, 21.
Stellite 6, 21, 236.
Stellite 21, 209, 267, 363.
Stellite 25, 116, 157, 163.
Stellite 31, 17, 223, 335, 363, 370.
Stellite 98M2, 267.
Stellite Star J, 267.
General, 65, 316.
He 1049 Alloy, 17, 335.
Heliarc Process, 237.
Hi-C Super-Hy-Tuf Steel, 222.
High Perm 49, 149.
Hipernik, 81, 149, 284.
Hipernik V, 81, 149, 284.
Hipersil, 149.
H Monel
See **Monel**
HR Crown Max Steel, 223.
HS-220 Steel, 221.
HS-1049, 363.
HTC Nickel
See **Nickel**
HY-65 Steel, 184.
HY-80 Steel, 184.
Hymu-80, 45, 81, 149, 284.
Hy-Tuf Steel, 221.

Inco 700, 338, 366.
Inco 702, 369.
Inco 713, 83.
Inco 803, 236.
Inco 901, 224.
Incoloy Alloys
Incoloy, 181, 309, 372.
Incoloy 804, 309.
Incoloy 901, 335.
Incolov T, 181.
Inconel Alloys
Inconel, 3, 20, 25, 55, 60, 85, 89, 156, 157, 163, 170, 181, 186, 189, 190, 191, 200, 204, 226, 228, 230, 236, 267, 269, 272, 302, 308, 309, 312, 336, 337, 338, 344, 368, 369, 370, 372.
Inconel 550, 51, 297.
Inconel 700, 297, 363.
Inconel 702, 157, 191, 200.
Inconel 713C, 372.
Inconel S, 181, 267.
Inconel X, 16, 20, 25, 54, 98, 116, 154, 159, 170, 181, 190, 191, 224, 225, 231, 267, 299, 331, 335, 338.
Inco-Weld A, 312, 314.
Inductovac Process, 155.
INOR-8, 86, 152, 230, 302, 376.
(*See also* **Hastelloy N**)

J-1570 Alloy, 200, 297, 367.

K-152B, **K-162B**, **K-163B**, **K-164B**, **K-183A**, **K-196** } *See* **Kentanium**
Kanigen Electroless Plating Process, 78.
Kanthal, 65.
KEL-F Elastomer, 21.
Kennametal, 229.
Kentanium Cermets
K 152B, 364, 365.
K 162B, 267, 364.
K 163B, 69.
K 164B, 364.
K 183A, 69, 364.
K 196, 364.
K Monel
See **Monel**
Kovar, 338, 344.
Kraq - O - Lite Plating Process, 41.

L-605 Alloy, 200.
Langalloy 20V, 60.
Lansin, 9.
LC and **LM Nicrobraz**, 192.
L Nickel
See **Nickel**
L.P.D. Steel, 288.
L-Silectron, 357.

M-1 Steel, 267, 288.
M-50 Steel, 288.
M-252 Alloy, 83, 154, 225, 262, 297, 362, 363, 367, 368.
M-730 Plating Addition, 141.
Magnesil, 45, 149.
Matrix M2 Steel, 288.
Mischmetall, 15.
ML-1700 Alloy, 363.
Monel Alloys
Monel, 2, 3, 21, 25, 32, 49, 55, 57, 59, 60, 69, 70, 87, 89, 95, 111, 129, 142, 153, 163, 170, 178, 181, 231, 236, 237, 246, 269, 308, 309, 316, 337.
Monel 402 and **403**, 181.
H Monel, 181, 269.
K Monel, 59, 170, 181, 269.
R Monel, 3, 181.
S Monel, 59, 181, 269.
Multimet Alloy, 267.
(*See also* **N-155**)
Mumetal, 149.

220 Nickel, **225 Nickel**, **499 Nickel** } *See* **Nickel**
N-155 Alloy, 157, 225, 367, 369, 370.
Nibrite, 8.
Nichrome, 11, 65, 297, 316, 336, 362, 369.
Nichrome V, 18, 20, 170, 191, 337.
Nickel
220 Nickel, 321.
225 Nickel, 321.
499 Nickel, 321.
A Nickel, 3, 25, 87, 170, 181, 264, 321.
F Nickel, 48.
G Nickel, 181, 267.
HTC Nickel, 87.
L Nickel, 267.
P-50 Nickel, 321.
S Nickel, 181.
Nicral D, 86.
Nicrobraz 10, 50 and **60**, 192.
Nicrotung, 53.
Ni-Hard, 47, 218, 358.
Nilo-K, 284.
Nimocast Alloys, 152.
Nimocast 90, 223.
Nimocast 242, 83, 223.
Nimocast 258, 69, 223.
Nimonic Alloys
Nimonic 75, 20, 52, 60, 157, 181, 237, 269, 340, 344, 374.
Nimonic 80, 20, 269, 362, 374.
Nimonic 80A, 20, 52, 83, 227, 237, 261, 269, 340, 374.
Nimonic 90, 20, 28, 31, 52, 69, 170, 230, 237, 260, 261, 269, 363, 374.
Nimonic 95, 69, 237, 374.
Nimonic 100, 20, 69, 83, 237, 374.
Nimonic 105, 374.
Nimonic DS, 60.
General, 65, 116, 151, 229, 336, 343, 370, 376.
Ni-O-Nel, 60, 163, 181, 309.
Ni-Resist, 112, 308, 309.
Type 1, 231, 237.
Type 2, 231.
Type 3, 21, 231.
Ni-Span C, 170.
Nitralloy Steel, 21.
Nitralloy N Steel, 288.
Nivco, 227.
Ni-Vee Type A, 356.

Orthonik, 149.
Orthonol, 45, 149, 358.

P-50 Nickel
See **Nickel**
Paralloy 20 Steel, 60.
Peerless 56 Steel, 293.
Peerless J Steel, 222.
Peraluman, 94.
Permalloy Alloys, 45, 46, 65, 81, 149, 284, 316, 358.
Permeron, 149.
Perminvar Alloys, 316, 358.
Petro-bond Sand Binder, 178.
P.H. 15-7 Mo Steel
See **Armco**
PH-55 Steels, 223.
Polypor Materials, 350.
Pyro-Plate Process, 373.
Pyro-Tung Process, 373.

R-235 Alloy, 157.
Raney Cobalt Catalyst, 125.
Raney Nickel Catalyst, 125.
Refractaloy 26, 370.
René 41 Alloy, 200.
R Monel
See **Monel**
Rokide A, 299.

S-590 Alloy, 370.
S-816 Alloy, 51, 223, 225, 262, 292, 297, 338, 362, 363, 370.
SCA-100 Cermet
Silectron, 149.
S Inconel
See Inconel
S Monel
See Monel
S Nickel
See Nickel
Sprayweld Process, 198.
Stainless W Steel, 331.
Stellite Alloys
See Haynes Stellite
Stupalith, 179.
Super Gleamax Bright-Nickel - Plating Solution, 9, 140.
Supermalloy, 45, 81, 149, 284.
Supermendur, 149, 357.
Super Tricent Steel, 222.

T-1 Steel, 184.
TC Ferry
See Ferry
Teflon, 236.
Thermenol Alloys, 68, 357.
Thermold J Steel, 14, 293, 294.
Timken 17-22A(S) Steel, 294.
Timken 16-25-6 Steel, 224, 292, 338.
Tran-Cor 3X, 149.
Transformer-A, 357.
Tricent Steel, 221, 287.

Udimet-500, 83, 153, 154, 334, 362, 363, 367, 369.
Udylite Bright - Nickel Additions 41 and 2RL 8.
UI 117-50 Ceramic, 19.
Unionmelt Welding Process, 96.
Unitemp 212 Steel, 155, 331.
U.S.S. Strux Steel, 222.
Utimet 500, 17, 335

Vac Cad Process, 259.
Vascojet 1000 Steel, 222.
Vitallium, 370.
Vycor, 11, 179.

W-545 Alloy, 335, 363.
Waspaloy, 83, 154, 367, 368.
WF-176 Steel, 223.
Worthite Steel, 60, 309.

X-50 Alloy, 335.
X-63 Alloy, 335.
X-8001 Alloy, 375.

Z-Silectron, 357.
Zircaloy, 61, 138.
Zircaloy 2, 199, 311, 338
Zircaloy 3, 200.
Zonax Bright Chromium Plating Solution, 9.

An up-to-date list of addresses of publishers of the periodicals mentioned in The Nickel Bulletin has been printed and we shall be pleased to send a copy to readers on request.

NAME INDEX TO VOLUME 32

Abrahamson, E. P. 365, 368.
Achter, M. R. 18, 106, 368.
Acker, J. T. 321.
Adams, G. R. 119.
Adams, W. S. 218.
Adès, L. 8.
Aggen, G. N. 188.
Ahearn, P. J. 288.
Ahern, S. A. 12.
Aitken, A. McL. 78.
Alexander, A. L. 160.
Alfonsi, B. 180.
Almqvist, G. 97.
American Electroplaters' Society, 42, 282, 283, 323, 327.
American Institute of Electrical Engineers, 44, 216.
American Society of Mechanical Engineers, 231.
American Society of Metals, 220, 245, 357.
American Society for Testing Materials, 3, 18, 37, 40, 44, 170, 171, 177, 182, 194, 213, 215, 224, 246, 254, 255, 269.
Amy, J. A. 16, 153, 224.
Anderson, J. C. 172.
Anderson, R. V. 60.
Anderson, W. A. 245.
Andrews, C. R. 156.
Antill, J. 67.
Arant, N. R. 47.
Arbuzov, M. P. 322.
Armstrong, T. N. 112.
Arrott, A. 357.
Arrowsmith, D. J. 8.
Atkinson, R. H. 140.
Atomic Energy of Canada, Ltd. 2.
Ault, G. M. 362.
Averbach, B. L. 260, 357.
Avraamov, Y. S. 336.

Babcock and Wilcox Company, 24.
Backensto, E. B. 57, 164.
Bacon, F. T. 173.
Bacon, R. A. 354.
Badger, F. S. 186.
Baerlecken, E. 299.
Balajiva, K. 196.
Baldwin, W. M. 51.
Ball, F. A. 98.
Ball, R. E. 45.
Bamberger, E. N. 200.
Bane, R. W. 138.
Banerjee, B. C. 75, 282.
Barker, R. C. 45.
Barraclough, S. 58.
Barrett, B. R. 245.
Barrett, C. A. 51.
Barton, J. W. 13.
Bastien, P. 343.
Battelle Memorial Institute, 9, 22, 25.
Beach, J. G. 211.
Beachem, C. D. 257.
Beacom, S. E. 177, 281.
Beamer, P. W. 366.
Bean, C. P. 357.
Beatson, E. V. 199.
Beauvais, C. 343.
Beck, F. H. 90, 305.
Becker, J. J. 357.
Beeskow, H. 353.
Belser, R. B. 178.
Belvedere, C. 224.
Belyakov, L. N. 336.
Benes, R. 165.
Benesovky, F. 67.
Benham, R. R. 140.
Bennett, D. G. 19.
Bennett, H. H. 236.
Bennett, J. A. 112.
Bernshtein, M. L. 292, 295.
Berry, J. 373.
Berry, J. M. 267.
Bertocci, U. 90.
Betteridge, W. 116, 151, 229.
Bever, M. B. 325.
Bhattacharyya, S. K. 173.
Bieber, C. G. 245.
Bigelow, W. C. 16, 153, 224.
Biggs, B. L. 361.
Binder, W. O. 119.
Birchenall, C. E. 37.
Birks, L. S. 225.
Bittmann, E. E. 254.
Blackie, M. S. 280.
Blanchard, J. R. 158.
Blanchard, R. 194.
Bloch, L. 172.
Blundy, P. D. 6.
Bobeck, A. H. 46.
Bockris, J. O'M. 211.
Bollman, W. 349.
Borachia P. 256.
Borodkina, M. M. 284.
Borrmann, G. H. 306.
Bott, H. B. 203.
Bowers, J. E. 356.
Bransom, S. 280.
Braun, M. P. 258.
Braun, W. J. 25.
Bray, R. S. 245.
Brien, R. E. 112.
Brindley, W. F. 56.
Brinkman, J. A. 322.
British Cast Iron Research Association, 1, 72, 150.
British Iron and Steel Research Association, 151.
British Non-Ferrous Metals Research Association, 1, 214, 351, 356.
British Standards Institution, 138, 139, 330, 350, 359.
British Steel Castings Research Association, 1.
British Welding Research Association, 328, 329.
Britton, S. C. 108, 143.
Brockway, L. O. 16, 224.
Brody, J. K. 138.
Brooks, E. J. 225.
Brooks, W. B. 374.
Brown, B. F. 259, 340.
Brown, J. F. W. 70.
Brown, J. T. 53, 335, 363.
Bryan, W. T. 55.
Bückle, C. 185.
Buckley, D. H. 266.
Buhr, R. K. 359.
Bukina, V. K. 177.
Bukowiecki, A. 94.
Bulina, J. 335, 363.
Bullock, G. 109.
Bunce, B. E. 7.
Bungardt, K. 83, 119, 159, 292.
Bünger, J. 120.
Burbank, R. D. 358.
Burkhardt, W.
Burling Smith, W. J. 198.
Burrows, C. F. 191, 193.
Burt, R. R. 114.
Bush, G. H. 108.
Busk, R. S. 245.

Caldwell, M. R. 251.
Calvert, L. D. 111.
Cameron, J. A. 112.
Campbell, J. E. 287.
Campbell, T. T. 145.
Canavan, H. M. 272.
Capel, L. 96.
Caplan, D. 157.
Carius, C. 90.
Carius, W. 235, 236.
Carlson, R. L. 287.
Carr, D. S. 54.
Carr, W. J. 357.
Carroll, K. G. 224.
Carruthers, M. E. 274.
Casey, A. T. 249.
Casey, F. W. 334
Cash, D. J. 151.
Castell, H. C. 41.
Castleman, L. S. 4.
Cataldi, H. A. 21.
Catterall, J. A. 209.
Cels, J. P. 174.
Chamblin, V. C. 6.
Chang, B.-C. 283.
Chang, W. H. 61.
Char, T. L. R. 176, 251.
Chaybany, A. 354.
Cheng, C. F. 21.
Child, H. C. 82.
Cibula, A. 1.
Clancy, W. P. 258.
Clark, C. C. 335.
Clark, C. L. 372.
Clark, J. J. 80, 284.
Clarke, M. 108, 143.
Clarke, W. E. 72.
Class, J. 311.
Clausing, R. E. 376.
Clauss, F. J. 51.
Cochardt, A. 117, 727, 333, 357.
Cohen, B. 14, 48.
Cohen, M. 111, 157.
Coldren, A. P. 264.
Committee for Standards, Measures and Measuring Instruments, Council of Ministers of U.S.S.R. 214.
Conger, R. L. 46.
Conrad, H. 261.
Contractor, G. P. 222.
Conway, B. E. 211.
Copson, H. R. 227.
Cordero, H. G. 172.
Cordovi, M. A. 372.
Corey, C. L. 224.
Corner, W. D. 107.
Couzy, J. 247.
Crussard, C. 86.
Crystal, H. 109.
Cubicciotti, D. 4.
Culbertson, R. P. 95, 310.
Cunningham, D. E. J. 144.
Cunningham, J. W. 335.
Cuthill, J. R. 115

Dale, J. J. 140.
Dandy, A. 280.
Danielson, E. 2.
Darmara, F. N. 138.
Dassarmo, B. 172.
Davey, P. 2.
Day, M. J. 118.
De Blois, R. W. 357.
Decker, R. F. 16, 367, 370.
Dedman, H. E. 293.
Defranoux, J. M. 309.
De Gromoboy, T. 144.
Deissler, R. 2.
Dell, R. M. 5.
Deutsch, G. C. 365.
Deutscher Normenausschuss, 73.
Dhosi, J. M. 183.
Dickinson, T. A. 78.
Dietz, G. 90.
Dietz, J. K. 220.
Diran, L. M. 99.
Disam, A. 353.
Dixon, R. H. T. 150.
Domnikov, L. 273.
Donoghue, H. G. 218.
Donovan, B. 172.
Donovan, M. 67.
Douglas, D. A. 226, 229, 295, 368.
Downey, R. C. 337.
Droegkamp, R. E. 199.
Dubpernell, G. 250.
Ducret, L. 250.
Dudek, R. F. 24.
Du Rose, A. H. 146.
Dyrkacz, W. W. 367.

Eberle, F. 290.
Ebling, H. F. 304.
Edeleanu, C. 22.
Edwards, J. 140.
Eian, C. 2.
Eisenhauer, J. J. 366.
Eisenkolb, F. 187.
Ek, C. H. 115.
El-Gendi, S. 212.
Elliott, C. R. 231.
Elman, I. B. 99.
Elser, F. 352.
Emmons, W. F. 193.
Engl, A. 298.
England, L. J. 250.
Engle, J. P. 162.
Epner, M. 185.
Ergang, R. 83.
Erikson, S.-E. 97.
Ernst, D. W. 11, 282, 283, 323.
Esmore, L. H. 140.
Etter, R. W. 215.
Evans, E. B. 51.
Evans, R. M. 302.
Evans, T. E. 121.
Everest, A. B. 219.
Everett, L. H. 138.
Everhart, J. L. 118, 169.

Fabian, R. J. 284.
Fanner, D. A. 107, 141.
Farago, F. 221.
Faulkner, W. H. 245.
Faust, C. L. 9.
Fedotov, I. D. 4.
Feduska, W. 201, 311.
Feisel, D. H. 333.
Ferguson, K. M. 24.
Ferguson, R. R. 159.
Ferré, S. 228.
Fieldhouse, I. B. 209.
Fink, F. W. 25.
Finsen, J. E. 272.
Fisher, A. O. 230.
Fisher, J. I. 286.
Fishlock, D. J. 259.
Fitzer, E. 228.
Fitzgeorge, D. 217.
Flemings, M. C. 360.
Flinn, R. A. 268, 366.
Flint, G. N. 233.
Floreen, S. 325.
Florence, T. M. 39.
Floyd, G. L. 162.
Fontana, M. G. 90, 91, 305.
Forgeson, B. W. 160.
Forsyth, F. R. 248, 249.
Fountain, R. W. 245, 365.
Fragetta, W. A. 204.
Frank, R. G. 224, 366.
Frankel, H. E. 112.
Franklin, T. C. 144.
Frazier, R. 2.
Freche, J. C. 263.
Freeman, J. W. 16, 51, 224, 264, 367, 370.
Frey, S. S. 41.
Friedberg, S. A. 178.
Friedl, B. E. 25, 303.
Fritz, J. F. 80, 284.
Fritzlen, G. A. 245, 363.
Frohberg, M. G. 39.
Frohlich, H. P. 248, 249.
Fry, H. 214.
Fusner, G. R. 225.

Galonian, G. E. 23, 306.
Gardner, M. 67.
Garofalo, F. 114, 265.
Gegner, P. J. 309.
Geiger, T. 260.
Gelles, S. H. 279.
Geneidy, A. 212.
General Electric Research Laboratory, 267.
Genty, B. 185.
Gerasimoff, P. 228.
Gerds, A. F. 20.
Gilbert, G. N. J. 150.
Gilbert, P. T. 299.
Gill, E. T. 196, 288.
Girard, R. G. 78.
Gittus, J. H. 254.
Glassick, C. E. 249.
Glenny, E. 68, 230.
Glicksman, R. 6.
Goetzel, C. G. 86, 185, 364.
Gold, V. 280.
Goldberg, D. C. 337.
Goldman, J. E. 178, 357.
Goodenough, J. B. 357.
Goodman, S. 221.
Goodwin, P. S. 79.
Goodwyn, J. 144.
Gorin, E. 173.
Goswami, A. 75, 282.
Gottwald, H. 256.
Gould, J. E. 80.
Gould, J. V. 328.
Gouwens, P. 373.
Graf, H. 39.
Gräfen, H. 271.
Graham, C. D. 357.
Graham, W. F. 195.
Grant, N. J. 332, 365, 368.
Gray, P. S. 340.
Grazen, A. E. 110.
Greathouse, W. D. 341.
Green, R. 360.
Greenblatt, J. H. 308.
Greene, N. D. 90, 91.
Greenwood, J. N. 12.
Gregory, E. 86, 185.
Grinthal, R. D. 266.
Gross, J. H. 112, 184.
Gross, M. R. 194.
Grosse W. 256.

Grunwald, J. J. 323.
Guard, R. W. 370.
Gudtsov, N. T. 292,
Gugan, D. 107.
Günther, G. 83.
Guthrie, G. L. 178.
Gyorgak, C. A. 297.

Haefner, K. 269.
Hague, J. L. 185.
Hahn, R. 11.
Hall, N. 213.
Hall, R. C. 149.
Hamaker, J. C. 220.
Hammond, C. M. 366.
Hammond, R. A. F. 107, 141.
Hamstead, A. C. 161.
Harpur, C. E. 218.
Harris, G. T. 82.
Hartbower, C. E. 112, 259.
Harwood, J. J. 290, 331, 365.
Hatch, W. P. 112.
Hausner, H. 342.
Hawkes, P. E. 115.
Hayes, P. A. 121.
Heavens, O. S. 143.
Hehemann, R. F. 113, 185, 362.
Heidenreich, R. D. 358.
Hempel, M. 370.
Henneke, H. 312.
Hibbs, L. E. 107, 172.
Hicklin, W. H. 178.
Higgs, D. G. 108.
Hill, R. M. 147.
Hinde, J. 95.
Hines, J. G. 23.
Hoar, T. P. 8, 23.
Hogan, C. 2.
Hoke, J. H. 290.
Holmes, K. D. 288.
Holsinger, F. J. 165.
Holt, M. L. 11.
Holzworth, M. L. 163.
Hoofdcommissie voor de Normalisatie in Nederland, 174.
Hopkinson, B. E. 204.
Hoppin G. S. 200, 338.
Houk, W. W. 276.
Hovorka, F. 174.
Howell, I. J. 140.
Hudson, F. 178.
Hudson, J. C. 302.
Hughes, H. 261.
Hugo, J. P. 57.
Hull, F. C. 205.
Hultgren, R. 110.
Humenik, M. 364.
Huntington, J. S. 138.
Hutchinson, F. 107.
Hütter, L. J. 216.

Ibragimov, S. S. 336.
Iida, Y. 5, 210.
Ilschner-Gensch, C. 5.
Institute of British Foundrymen, 1.
Institution of Metallurgists, 209.
International Nickel Company, Inc. 3, 7, 43, 111, 112, 159, 174, 181, 182, 185, 228.
Iron and Steel Institute, 302.
Irvine, K. J. 331.
Iske, F. W. 82.
Iwanski, J. S. 335.

Jackson, E. G. 288.
Jackson, R. C. 81.
Jackson, R. E. 46.
Jackson, W. J. 1.
Jacobs, W. D. 211.
Jaffee, R. I. 336.
Jech, R. W. 366.
Jellinghaus, W. 80.
Jenkins, I. 65.
Johnson, J. W. 4.
Johnson, R. L. 266, 301.
Johnston, J. R. 261, 262, 297, 362.
Jonassen, H. B. 6.
Jones, C. A. 245.
Jones, D. 308.
Jones, H. N. 122.
Jones, J. B. 338.
Jones, M. H. 42.
Jones, P. W. 328.
Jones, R. A. 224.
Jones, T. E. M. 329.

Kaddou, A.-F. K. 359.
Kaltenhauser, R. H. 237.
Kaminskii, E. Z. 86.
Kanter, J. J. 269.
Kape, J. M. 140.
Kato, T. R. 236.
Kattus, J. R. 19. 182, 293, 294.
Kaufmann, A. R. 279.
Keil, H. L. 248, 249.
Keller, J. D. 47.
Kelley, C. M. 4.
Kelly, J. F. 195.
Kennedy, C. R. 295.
Kennedy, E. M. 14.
Kennedy, S. W. 111.
Kieffer, R. 67.
Kikeli, P. S. 221.
King, P. P. 275.
King, R. 2.
Kingery, W. 2.
Kirkby, H. W. 371.
Klier, E. P. 221.
Kloos, K. H. 341.
Kneller, E. 11.
Kobayashi, H. 90.
Koch, W. 49.
Kochanovska, A. 73.
Kochendörfer, A. 46, 47.
Koehler, W. A. 212.
Kollrack, R. 260.
Kolotyrkin, Y. M. 90.
Kondrashev, A. I. 258.
Konev, Y. K. 336.
Kononenko, N. I. 177.
Konstantinova, G. S. 283.
Korchynsky, M. 365.
Kraft, R. W. 268.
Kramer, D. 106.
Kramer K. H. 256.
Krauss, G. 260.
Krijn, G. C. 6.
Krisch, A. 49.
Kriutchkov, N. F. 4.
Krivobok, V. N. 94.
Kropschot, R. H. 195.
Krulikovskaya, M. P. 322.
Kula, E. B. 183.
Kushner, J. B. 42.
Kwiatkowski, Z. 75, 141.

Lahr, A. F. 269.
Lainer, V. I. 283.
Lam, D. G. 229.
Lan, C. 110.
Lang, F. S. 227.
Lang, J. I. 231.
Langenberg, F. C. 118.
Lanzara, A. A. 124.
Larrabee, C. P. 82.
Lavendel, H. W. 364.
Lawthers, D. D. 368.
Leach, J. S. Ll. 325.
Lechnick, W. 89.
Lee, E. W. 81.
Lee, W. T. 142.
Lefort, H. G. 19.
Leggett, R. D. 343.
Lena, A. J. 245.
Lenel, F. V. 366.
Lennartz, G. 119, 292.
Lents, R. O. 296.
Lessley, H. L. 294.
Levick, R. 237, 376.
Levinstein, M. A. 297, 336.
Levy, C. 324.
Lewis, C. F. 222.
Lewis, L. 98.
Leyda, W. E. 290.
Liebson, M. 274.
Linde, D. 2.
Linden, H. 312.
Lindh, G. 96, 344.
Linford, H. B. 323.
Linnert, G. E. 203.
Livshits, B. G. 336.
Llewellyn, D. T. 331.
Llewelyn, D. T. 261.
Lockington, N. A. 142.
Löfblad, B. 96, 344.
Logan, H. L. 339.
Lorenz, K. 299.
Lowry, L. 342.
Lozier, G. S. 6.
Lula, R. A. 188.
Lund, J. A. 72.
Lundsten, R. H. 357.
Lux, B. 335.
Luykx, J. M. M. 210.
Lyon, C. B. 248.

Machlan, L. A. 185.
Machlin, E. S. 106, 138.
Machu, W. 212.
Mackay, W. B. F. 219.
Mackiw, V. N. 245.
MacNairn, J. 106.
Mahan, W. M. 279.
Mallett, M. W. 20.
Manenc, J. 115, 185.
Manjoine, M. J. 368.
Manly, W. D. 189.
Manning, G. K. 287.
Marin, J. 256.
Marshall, M. W. 188, 273.
Martin, D. L. 267.
Martin, M. J. C. 12.
Mason, J. F. 237, 308.
Mathauser, E. E. 371.
Mayer, G. 196.
McAndrew, J. B. 61.
McCormick, W. R. 171.
McDowell, D. W. 204.
McElrath, T. 71.
McGeary, R. K. 275.
McGee, R. L. 287.
McGlasson, R. L. 341.
McHenry, H. T. 368.
McKee, J. M. 271.
McKinnell, W. P. 90.
McPherson, B. 182.
Medovar, B. I. 296.
Mehan, R. L. 116.
Mehl, R. F. 245.
Meinhart, W. L. 269.
Meissner, J. 215.
Melbourne, S. H. 143.
Melcher, N. B. 279.
Meredith, R. 377.
Meyer, F. H. 236.
Michelitsch, M. 349.
Michenry, H. T.
Mietka, M. 353.
Mihalisin, J. R. 224.
Mikesell, R. P. 301.
Mikus, E. B. 258.
Millis, K. D. 112.
Mills, E. C. 140.
Ministry of Defence, 197.
Minkina, E. A. 210.
Miroshkina, E. M. 334.
Mishler, H. W. 289.
Mitchell, D. L. 149.
Moeller, C. E. 220.
Mohler, J. B. 43, 216.
Mond Nickel Company, Ltd. 98, 150, 198, 209, 219, 288, 356.
Moore, D. W. 11, 46.
Morehouse, C. K. 6.
Morgan, A. R. 307.
Morgan, P. A. 237, 376.
Morgan, W. A. 222, 359.
Morris, F. G. 214.
Morris, J. C. 231, 299.
Morris, R. J. 363.
Morrogh, H. 1.
Moss, M. 2.
Mott, N. S. 223.
Mueller, J. J. 60.
Muench, C. F. 288.
Mukhin, C. G. 123.
Munro, B. S. 356.
Murphy, N. F. 40.
Musick, V. S. 21.

Nagayama, M. 90.
National Advisory Committee for Aeronautics, 2, 16, 51, 297, 370.
National Aeronautics and Space Administration, 261, 262, 263, 266, 334, 369, 371.
National Association of Corrosion Engineers, 162, 164, 195, 236, 237.
National Bureau of Standards, 185, 195.
National Gas Turbine Establishment, 68.
Naumann, F. K. 235, 236.
Necheles, R. 61.
Nederveen, C. 96.
Neely, W. L. 112.
Nel, L. G. 57.
Nesbitt, E. A. 358
Newhouse, D. L. 225.
Newkirk, J. B. 245.
Newman, D. R. 282.
Neymark, R. S. 268.
Nielsch, W. 211.
Nielsen, N. A. 90, 303.
Nohl, H. 335.
Norcross, H. H. 144.
Norden, W. E. 310.
Norman, T. E. 285.
Northwood, J. E. 230.
Norton, J. T. 363.
Norton, M. R. 258.
Nowacki, L. J. 303.
Nussear, W. O. 95.
Nutting, J. 209.

Oak Ridge National Laboratory, 152, 190, 229.
Ogburn, F. 282, 283, 323.
Ogilvie, R. E. 279.
Okamoto, G. 90.
Olsen, K. M. 171.
Olson, O. H. 231, 299.
Orner, G. M. 260, 287.
Osipov, K. A. 334.
Osman M. G. 281.
Ostrowski, E. J. 279.
Otley, D. J. 218.
Ott, G. E. 285.
Otto, G. 46, 47.
Owen, L. W. 141, 252.
Oza, B. C. 40.
Ozaki, S. 210.

Paine, T. O. 357.
Palchuk, N. Y. 123.
Panikkar, S. K. 251.
Paret, R. E. 94, 165.
Parfenov, V. A. 84, 85.
Parikh, N. M. 364.
Parr, J. G. 13.
Pasnak, M. 357.
Pateau, L. 250.
Patriarca, P. 376.
Patterson, W. 82.
Pavlov, V. A. 4, 283.
Paxton, H. W. 245, 343.
Pearce, R. F. 245.
Pease, G. R. 98, 204.
Peckner, D. 231.
Pennington, W. A. 112.
Penrice, T. W. 66.
Perks, R. P. 276.
Perriton, R. C. 95.
Perry, E. R. 199.
Peturson, B. 248, 249.
Peveturina, I. A. 283.
Pfeiffer, H. 88.
Pfeil, L. B. 151.
Philip, T. B. 70.
Phillips, J. H. 375.
Phillips, L. E. 305.
Pickering, F. B. 331.
Pickett, J. 106.
Pickles, A. E. 71, 205.
Pier, G. 234, 270.
Pierce, W. J. 146.
Pierson, R. E. 165.
Pigan, E. A. 190.
Piontelli, R. 90.
Pitler, R. K. 367.
Pitt, C. H. 39.
Pitter, R. K. 115.
Piwowarsky, E. 82.
Podlipec, F. J. 236.
Pope, J. A. 217.
Porter, E. O. 286.
Powell, R. W. 2.
Pray, H. A. 25.
Preobrazhenskaya, N. V. 210.
Preston, J. B. 19, 294.
Preston, P. F. 231.
Pride, R. A. 371.
Priscott, B. H. 141.
Probst, H. B. 368.
Promisel, N. E. 331.
Prötzl, M. 49.
Przybycien, W. 2.
Pugh, E. W. 79.
Pugh, J. W. 366.

Quarrell, A. G. 209.

Radavich, J. F. 369.
Ragland, F. J. 191.
Ramanathan, V. R. 142.
Rathenau, G. W. 357.
Raub, E. 75, 214, 352, 353.
Raudebaugh, R. J. 113. 245.
Ray, K. R. 172.
Raynor, G. V. 209.
Rechlin, F. F. 193.
Recht, H. L. 173.
Redden, T. K. 366.
Reddy, A. K. N. 143.
Redmond, J. C. 363.
Reed, R. E. 343.
Reed, R. P. 301.
Reid, B. J. 12.
Reid, F. H. 140.
Resh, S. H. 275.
Reynolds, E. E. 115, 367,
Rhoda, R. N. 140.
Rhodin, T. N. 90.
Richards, C. E. 254.
Richmond, E. M. 367.
Richmond, J. C. 115, 190, 369.
Riddell, F. L. 179.
Riley, B. J. 177.
Rimrott, U. A. 256.
Riott, J. P. 279.
Roberts, H. 52.
Roberts, J. A. 170.
Roberts, S. 279.
Roberts, W. H. 149, 323.
Robertshaw, T. L. 362.
Robertson, W. D. 245.
Robins, D. A. 68.
Roche, T. K. 85, 152.
Roe, W. P. 19.
Roesch, K. 225.
Rhode, H. 49.
Roller, D. 156.
Röllig, H.-E. 187.
Rosene, R. B. 162.
Rosenthal, P. C. 359.
Ross, A. M. 2.
Rousselot, G. E. 77.
Rousselot, R. H. 77.
Rowan, W. H. 145.
Rowe, E. H. 288.
Rowe, J. P. 367, 370.

Rowe, L. C. 197.
Rowe, R. J. 355.
Rozenberg, V. M. 86, 210.
Rozic, E. J. 290.
Rubin, A. I. 184.
Runolinna, U. 218.
Russ, J. J. 220, 337.
Rutherford, J. J. B. 113, 372.
Ruttmann, W. 298, 314.
Ruzek, J. M. 310.

Sachs, K. 143.
Sadowski, E. P. 113.
Safonnikov, A. N. 296.
Safranek, W. H. 9, 145, 303.
Sageau, A. 247.
Sager, G. 2.
Salkind, A. J. 349
Samans, C. H. 272.
Samuel, R. L. 142.
Sampson, M. P. 6.
Sato, N. 90.
Saubestre, E. B. 73, 175.
Sautter, F. 214.
Sawyer, R. 2.
Schab, H. W. 89.
Schaer, G. R. 211.
Schaffnit, W. O. 302.
Scharfstein, L. R. 56.
Scheil, M. A. 304.
Schenck, H. 39.
Scheuerman, W. 151.
Schiller, A. 314.
Schillmoller, C. M. 237, 308.
Schinn, R. 298, 314.
Schmatz, D. J. 327.
Schmidt, D. G. 179
Schmidt, G. 352.
Schmitt, R. J. 93.
Schneider, F. 96.
Schoefer, E. A. 55, 187.
Schofield, F. 2.
Schrader, A. 49.
Schubert, K. 216.
Schüller, H.-J. 271.
Schurin, B. 231.
Schwaab, P. 271.
Schwabe, K. 90.
Schwartzbart, H. 61.
Schwarzkopf, W. M. 332.
Schwenk, W. 234.
Schwope, A. D. 366.
Scott, E. H. 288.
Seifert, R. 2.
Seigle, L. L. 4.
Sellier, E. 310.
Semchyshen, M. 365.
Semmel, J. W. 369.
Serravalle, G. 90.
Setapen, A. M. 124
Seyb, E. J. 145.
Shahinian, P. 18, 106, 368.
Shaw, R. E. 144.
Shaw, S. W. K. 230.
Shea, J. F. 246.
Shearer, A. W. 259.
Sheehan, J. P. 286.
Shelton, D. C. 218.
Shelton, S. 2.
Shephard, S. W. 303.
Sherwood, R. C. 357.
Shewmon, P. 138.
Shinyaer, A. Y. 253.
Shreir, L. L. 144.
Shulman, R. G. 357.
Shul'ts, A. L. 177.
Shyne, J. C. 327.
Sideris, G. 81, 148.
Siebert, C. A. 258.
Siegfried, W. 335.
Signorelli, R. A. 261, 262, 362.
Silman, R. 213.
Silverman, L. 2, 276.
Singh, T. P. 359.
Singley, W. J. 375.
Sivertsen, J. 179.
Sjoberg, J. W. 57, 164.
Slaughter, G. M. 376.
Slowinski, M. F. 124.
Slunder, C. J. 89.
Smart, A. 77.
Smeltzer, W. W. 138, 180.
Smith, A. A. 344.
Smith, A. J. 148.
Smith, D. C. 361
Smith, D. O. 357.
Smith, G. V. 114.
Snowden, P. P. 92.
Society of Automotive Engineers, 180, 203, 284, 288, 290, 297.
Sommer, K. 8, 144, 165.
Sopher, R. P. 15, 289.
Soppet, J. F. 98.
Sorkin, G. 57.
Sosin, A. 322.
Sotnichenko, A. N. 334.
Sourirajan, S. 173.
Southwell, C. R. 160.
Spähn, H. 323.
Speiser, R. 90.
Spencer, L. F. 215, 310, 376.
Spicer, K. M. 98.
Spretnak, J. W. 360.
Springsteen, D. F. 297.
Sproat, R. L. 189.
Srawley, J. E. 257.
Sree, V. 176.
Stadelmaier, H. H. 216.
Staehle, R. W. 305.
Stapleton, B. 284.
Starke, K. 249.
Starr, C. 2.
Steele, M. C. 250.
Steiger, A. J. 75.
Steiner, J. E. 256.
Steinitz, R. 364.
Stern, M. 235.
Sternheim, G. 90.
Steunenberg, R. K. 248.
Stewart, J. E. 369.
Stout, R. D. 184.
Stover, E. R. 110.
Strauss, S. W. 259, 327.
Streets, G. A. 374.
Streicher, M. A. 163.
Stutzman, M. J. 17, 335.
Sucksmith, W. 12.
Sulmont, A. 343.
Svistunova, Z. V. 295.
Swales, G. L. 59, 196, 198, 288.
Swindeman, R. W. 229.
Szmidt, H. 141.
Szmidt, K. 75.
Szymanski, W. 71.

Takei, H. 246.
Tamhankar, R. 86.
Tanczyn, H. 188.
Tangel, O. F. 246.
Taylor, H. F. 360.
Taylor, R. 186.
Taylor, T. A. 68, 230.
Tebo, F. J. 170.
Templeton, H. C. 309.
Thirsk, H. R. 144.
Thomas, D. E. 374.
Thomas, H. 325.
Thompson, D. H. 341.
Thompson, E. G. 296.
Thompson, J. 119, 342.
Thompson, J. H. 231.
Thornton, A. E. 117.
Thornton, H. R. 190.
Tighe, N. J. 115.
Tipler, W. 88.
Tipoman, M. 322.
Tisinai, G. F. 272.
Title, R. S. 46.
Tomaschow, N. D. 90.
Townshend, B. 286.
Tragert, W. E. 375.
Travina, N. T. 86.
Troiano, A. R. 113, 185, 222.
Troughton, A. G. H. 81.
Trubetskova, R. I. 292.

Uhlig, H. H. 90, 106.
U.K. Atomic Energy Authority, 107, 121, 122, 284.
U.S. Atomic Energy Commission, 2, 23, 85, 98, 149, 163, 170, 248, 295, 296, 302, 306.
U.S. Bureau of Mines, 245, 279.
U.S. Bureau of Ships, 195.
U.S. Naval Engineering Experiment Station, 188, 193, 194.
U.S. Naval Research Laboratory, 18, 160, 257.
U.S. Navy Bureau of Aeronautics, 185.
U.S. Office of Ordnance Research, 51.
U.S. Office of Tecbnical Services, 305, 342.

Vaaler, L. E. 145.
Vacek, J. 247.
Valentiner, S. 38.
Van Delinder, L. S. 161.
Van Dusen, M. 2.
Van Hook, J. O. 248.
Van Houten, G. R. 38, 69.
Van Veldhuizen, H. 210.
Van Vleck, J. H. 357.
Veeriah, K. 39.
VerSnyder, F. L. 362, 370.
Veyrac, R. 247.
Videm, K. 307.
Vinokur, B. B. 258.
Vitovec, F. H. 292, 334.
Vlannes, P. N. 259, 327.
Vosteen, L. F. 89.

Wachtman, J. B. 229.
Waddams, J. A. 227, 340.
Wade, W. R. 334.
Wadsworth, M. E. 39.
Wagner, H. J. 360.
Wagner, V. L. 6.
Waindle, R. F. 170.
Wait, J. D. 275.
Walker, R. J. 96.
Wambold, J. 363.
Wanklyn, J. N. 308.
Warner, J. P. 245.
Warren, D. 232, 233.
Waters, W. J. 261, 263.
Watkins, B. 339.
Watkinson, J. F. 65.
Watmough, T. 373.
Watson, J. F. 280.
Weaver, C. 147.
Weber, E. P. 366.
Weeks, J. 2.
Weeton, J. W. 262, 362.
Weigand, H.-H. 159.
Weik, H. 83.
Weimer, D. E. 324
Weir, J. R. 226.
Welding Research Council, 113, 274.
Wernick, J. H. 169.
Wert, C. 179.
Wessel, E. T. 326.
West, H. J. 144.
West, J. M. 92.
Westbrook, J. H. 363.
Wetzlar, K. 292.
Wheelahan, E. J. 293.
Whelan, M. J. 300.
White, G. K. 138.
White, J. A. 124.
Whitmore, R. W. 114.
Whitney, F. L. 230.
Wiedmann, H. 80.
Wiegand, H. 341.
Wiester, H.-J. 270, 271.
Wiggin, Henry and Company, Ltd. 87, 88, 89, 229, 254, 269, 376.
Wilder, A. B. 372.
Wilke-Dörfurt, U. 325.
Wilkins, D. H. 107, 172, 182.
Williams, H. J. 357.
Williams, J. 67.
Williams, W. L. 188.
Wilman, H. 143.
Wilson, J. E. 53.
Wilson, W. L. 309.
Winchester, C. L. 79.
Wink, W. 80.
Winkler, O. 67.
Wisander, D. W. 301.
Wolf, J. E. 45.
Wood, D. R. 223.
Wood, N. 159.
Woods, S. B. 138.
Worn, D. K. 66, 210.
Wright Air Development Center, 11, 14, 17, 19, 149, 153, 158, 190, 191, 264, 266, 284, 286, 287, 288, 289, 290, 292, 293, 294, 299, 334.
Wright, H. R. 70.
Wright, J. C. 227, 340.
Wulff, J. 110.
Wynne-Jones, W. K. F. 144.

Yankee Atomic Electric Company, 98.
Yeager, E. 174.
Yeager, J. 174.
Yeates, R. L. 144.
Yerkovich, L. A. 153 294.
Yoe, J. H. 211.
Young, J. G. 326, 344.
Yuko, G. A. 13.

Zackay, V. F. 327.
Zajdowski, J. 42.
Zak, T. 75, 141.
Zaletaeva, R. P. 56.
Zeuner, H. 225.
Zibulsky, H. 124.
Zieman, W. H. 358.
Zimmerman, W. F. 224.
Zirinsky, S. 54.
Zitter, H. 233.
Zlatin, N. 328.
Zotos, J. 288.

PATENTS INDEX

Adler, O. E. 28.
Allied Chemical Corporation, 239.
Alter, L. 31.
Althouse, J. G. 30.
Amchem Products, Inc. 132.
American Cyanamid Company, 127.
Anger, E. M. 130.
Armco Steel Corporation, 318.

Bachmann, F. 126.
Banks, R. M. 127.
Bart Laboratories Company, Inc. 27.
Bechtold, J. H. 29.
Becking, D. H. 27.
Bell, R. C. 127.
Berk, F. W., and Company, Ltd., 240.
Binder, W. O. 132.
Birmingham Small Arms Company, Ltd. 28, 31.
Boegehold, A. L. 130.
Borg-Warner Corporation, 125.
Bowles, W. S. 132.
Brazier, J. G. 127.
Brennan, J. B. 125.
British Dielectric Research, Ltd. 27.
British Driver-Harris Company, Ltd. 131.
British Insulated Callender's Cables, Ltd. 127, 129, 239.
British Oxygen Company, Ltd. 125.
Brown, H. 27.
Brush, W. E. 132.
Budd Company, 316.
Bungardt, K. 30.
Bureau d'Etudes Industrielles Fernand Courtoy, 241.

Cape, A. T. 240.
Carman, E. H. 28.
Carpenter Steel Company, 317, 318.
Carr, D. S. 27.
Carrigan, C. E. 317.
Champion Spark Plug Company, 129.
Chesworth, J. 129.
Chrysler Corporation, 27, 29.
Chynoweth, W. 316.
Coast Metals, Inc. 31, 240.
Commissariat a l'Energie Atomique, 32.
Commonwealth Engineering Company of Ohio, 27, 28, 128, 315.
Compagnie Française Thomson-Houston, 29.
Cooper Alloy Corporation, 131.
Coy, C. L. 129.

Davey, E. L. 129.
Davis, G. L. 29.
Dehydag Deutsche Hydrierwerke G.m.b.H., 126.
Delange, M. 32.
Delta - Kühlschrank G.m.b.H., 132.
Deutsche Edelstahlwerke A.G., 30, 317.
Dow Chemical Company, 125.
Drummond, F. E. 28, 128.
Duraloy Company, 130, 317.
Duriron Company, Inc. 132.

Electric Steel Foundry Company, 131.
Esso Research and Engineering Company, 239.
Etabls. E. Jaeger, 129.

Fahlberg-List G.m.b.H., 238.
Fabian, R. W. 316.
Fairchild Engine and Airplane Corporation, 317.
Fink, L. E. 131.
Flint, G. N. 240.
Foreman, J. W. 132.
Fraser, W. M. 132.
Frenchtown Porcelain Company, 29, 128.
Furman, W. F. 317.

General Electric Company, 28, 30, 128.
General Motors Corporation, 127, 129, 130, 133.
Gentry, C. H. R. 29.
Graham, J. W. 133.
Gray, A. G. 315.
Gregg, J. F. 239.

Hadfields, Ltd. 31.
Hanink, D. K. 133.
Hanson - Van Winkle - Munning Company, 239.
Harrison, H. T. 317.
Hayden, W. 31.
Hays, S. A. 127.
Heger, J. J. 131.
Hodge, J. M. 131.
Hoffman, J. F. 129.
Homer, H. J. 128.
Horizons, Inc. 239.
Howards of Ilford, Ltd. 126.

Irish, C. R. 130.

Jatczak, C. F. 316.
Jendrzynski, H. J. 127.

Kardos, O. 239.
Karmitz, P. I. 315.
Kates, L. W. 129.
Keegan, B. 131.
Kegerise, W. R. 317, 318.
Kennametal, Inc. 133.
Köster, W. 317.
Krüger, G. 29.

Lallement, G. 315.
Lanpher, B. T. 317.
Larrimore, R. M. 318.
Lindenblad, N. E. 30.
Linnert, G. E. 318.
Losco, E. F. 29.
Low, S. 316.
Lukens Steel Company, 30.
Luks, D. W. 29, 128.

Mannesmann A. G. 318.
Manufactures de Produits Chimiques du Nord Etablissements Kuhlmann, 315.
Margolis, D. S. 27.
Marsh, P. R. 131.
Marvin, P. R. 27.
Maxted, E. B. 125.
Michael, G. 126.
Middleham, T. H. 31.
Milbourne, C. G. 315.
Miller, E. L. 26.
Miller, S. A. 125.
Millis, W. T. 29.
Mond Nickel Company, Ltd. 129, 130, 239, 240, 317, 318.
Mott, N. S. 131.
Mullard Radio Valve Company, Ltd. 29.
Murray, W. Y. 129.

Nack, H. R. 315.
National-Standard Company, 28.
Neumann, R. P. 239.
North American Aviation, Inc. 127.
Novak, L. J. 128.

Oliver, D. A. 31.

'Patelhold' Patentverwertungs- und Elektro- Holding A.G. 128.
Peppiatt, E. G. 126.
Perkins, R. A. 132.
Pinazzi, C. P. 315.
Polymer Corporation, Ltd. 26.
Powell, J. 128.
Price, E. R. 133.
Puchnin, E. G. 29.
Pure Oil Company, 26.

Radio Corporation of America, 30.
Rait, J. R. 31.
Régie Nationale des Usines Renault, 26.
Reynaud, F. 238.
Reynolds, E. H. 127, 239.
Rheinpreussen Aktiengesellschaft für Bergbau und Chemie, 26.
Riedel, A. 126.
Riedel and Company, 126.
Robinson Bros., Ltd. 126.
Rosenberg, S. J. 130.
Roth, A. 238.
Ruhrchemie A.G., 129.

Sakhatunov, Y. S. 29.
Sauteron, V. 32.
Scanlan, J. P. 31.
Schwarzkopf Development Corporation, 31.
Schweig, B. F. 128.
Shen, T. E. 27.
Siemens Planiawerke A.G. für Kohlefabrikate, 133.
Sienczyk, J. L. 316.
Sintercast Corporation of America, 130, 133.
Skinner, E. N. 240.
Smith, R. 131, 318.
Société d'Electro-Chimie, d'Electro - Métallurgie et des Aciéries Electriques d'Ugine, 238.
Sperner, F. 317.
Steinkohlen-Elektrizitäts A.G., 129.
Straumann, F. 29.
Straumann, R. 29.
Svchrovsky, H. 30.
Sylvania Electric Products, Inc. 129.

Tarr, C. O. 131, 318.
Teasel, R. C. 129.
Telefunken G.m.b.H. 128.
Thompson, S. A. M. 126.
Thomson, R. F. 129.
Tiarco Corporation, 126.
Tickle, W. H. F. 127.
Timken Roller Bearing Company, 316.
Topelian, P. J. 126.
Triffleman, B. H. 316.

Udylite Research Corporation, 27.
Union Carbide Corporation, 131, 132.
United Aircraft Corporation, 28.
United Gas Improvement Company, 315.
U.K. Atomic Energy Authority, 126.
U.S. Atomic Energy Commission, 315, 316.
U.S. Secretary of the Navy, 130.
U.S. Steel Corporation, 131, 316, 318.

Vertes, P. 32.

Wagner, F. C. 239.
Walker, W. A. 127, 239.
Wall Colmonoy Corporation, 132.
Walton, C. S. 316.
Ward, J. O. 31.
Webb, F. B. 240.
Webb, J. P. 29.
Westinghouse Electric Corporation, 29, 132.
Westinghouse Electric International Company, 130.
White, W. F. 316.
Wicker, R. J. 126.
Wiggin, Henry and Company, Ltd., 131.
Winstrom, L. O. 239.
Wood, D. R. 239.
Woolard, T. L. 318.
Worn, D. K. 240.
Wyche, E. H. 131.

Zimmer, F. 241.

THE MOND NICKEL COMPANY LIMITED
THAMES HOUSE · MILLBANK · LONDON, S.W.1

PRINTED IN ENGLAND *by* WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON, S.W.1